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SOME ELECTROPHYSICAL CONDITIONS DETERMINING LIGHTNING SURGES.*

BY

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THE nature of lightning surges in transmission systems is influenced by given electrostatic and electrodynamic conditions in the thunderstorm cloud. Of importance in this respect is the intensity of the field, the distributions of the volume charge and the discharging character of the lightning. It is not possible to give a theoretical analysis of these different factors in agreement with the real conditions in the thunderstorm atmosphere. To establish an unfailing precalculation of the discharging character of lightning is thus impossible. Only by concrete and direct observations can we gain a true understanding of the nature of lightning.

On the other hand, when it is necessary to procure a fundamental view of the general electrophysical conditions of the lightning surges, it may be of some interest to take into consideration some theoretical speculations.

1. DISTRIBUTION OF CHARGE AND CALCULATION OF THE FIELD FORCE.

The electric fields of thunderstorms are defined by the suspended electrically charged particles in the thunderstorm atmosphere. For an exact calculation of the field force, it

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is necessary to know the magnitude of charge per volume unity and its geometrical distribution, while the fact is that the field force can be calculated by an integration of the volume charges. It has not yet been possible to get any observations about the distribution of the volume charge in the thunderstorm clouds and, when calculating, it is thus quite necessary to make some simple assumptions.

The most elementary calculation can be performed by supposition of a uniform charge distributed within a sphere. The charge can in such a case be considered as concentrated at the center of the sphere. We have calculated the field for such distribution in order to secure an estimate of the dimensions of the field force. The uniform charge has been supposed to be within a sphere with a radius of 10^3 meter and with the lowest point of the sphere 10^3 meter above the earth's surface. The water quantity of the cloud has been estimated to amount to 4 grams per cubic meter. If this quantity is supposed to fall to earth on a surface of the great circle of the sphere, the quantity corresponds to a precipitation height that is not too high compared with the amount of water that generally can be concentrated within a thunderstorm cloud. With reference to P. Gschwend's [1] observations of the electric charge of rain drops in thunderstorms, each gram of water is supposed to contain 5 electrostatic units. With a water quantity of 4 grams per cubic meter, the total water quantity of the cloud becomes thus 16.8×10^9 gram, and the charge $5 \times 16.8 \times 10^9 = 8.4 \times 10^{10}$ E.S.U. or about 28 coulomb. The calculated field force with the earth's surface insulated becomes thus about 60 kilovolts per meter. If the surface is supposed to be quite conducting, the Lord Kelvin method of images leads to a doubling of the field force.

Sometimes the real conditions are better approximated by supposing, as Seeliger [2] has done, that the charges are distributed in a cylindrical volume. The field force dv/dz in

[1] P. Gschwend, "Jahrbuch der Radioaktivität und Elektronik," Bd. 7, 1, 65, p. 62, Leipzig, 1920.

[2] R. Seeliger, *Sitzber. der Wien. Akad. der Wissenschaften*, 125, 9, Wien, 1916.

the axial direction is in that case calculated by the formula:

$$\frac{dv}{dz} = 2\pi \int z dz \int_0^a \rho \frac{r dr}{(r^2 + z^2)^{3/2}}, \qquad (1)$$

where z is the height, a the radius and ρ the volume charge. If ρ is supposed to be independent of r and z, ρ can be substituted by a mean value and (1) becomes:

$$\frac{dv}{dz} = 2\pi\rho\{z_2 - z_1 + \sqrt{z_1^2 + a^2} - \sqrt{z_2^2 + a^2}\}. \qquad (2)$$

In (2), dv/dz is the field force at the point $z = 0$ for the cylinder with its end surfaces between z_1 and z_2. In reality, it is not quite possible to consider ρ independent of r and h in (1). It is convenient to calculate with the formula when it is necessary to take into consideration the slow variations of the field force and the field polarity. The variations in such a case may easily be explained by charged water particles which are falling with a defined velocity to earth, within a cylinder. When the cylinder axis is inclined to the earth's surface, the vertical potential gradient can be found by multiplying the value of dv/dz above by the cosine of the axis' angle. As an acceptable example, I have calculated dv/dz for the following vertical cylinder. Its lower plane is supposed to be 0.5 km. above ground, its radius is 0.2 km. and its height = 2 km. The volume charge is supposed to be 20 E.S.U. per cubic meter. If the earth's surface is supposed to be a perfect conductor, the vertical gradient becomes about 100 kv. per meter. It is not possible by the formula (1) to calculate the local field concentrations at the edges of the cylinder. In order to perform such a calculation, it is necessary to suppose the uniform charge distributed within a rotation-ellipsoid. The mathematical results are in such a case very complicated and we recommend it to be more convenient to perform a direct sounding measurement of the equipotential surfaces on a thunderstorm cloud model. The measurements can be performed with a water drop collector, and we have only to establish a probable average

charge on the model. Also. the field distribution easily can be observed by the soundings for such special parts of the cloud model where a mathematical calculation would be impossible to perform.

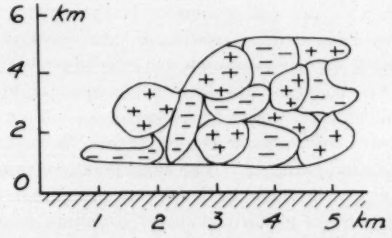
By direct observations of thunderstorm fields, we have found gradients of 100 to 150 kv./m. The order of magnitude of these values is in full agreement with either calculated values where the possible uniform charge has been supposed to be distributed in spheres, or cylinders, or else with observed values from models of clouds with the average charge distributed along surfaces of a given curvature.

It is obvious that more concentrated fields must be found at discontinuous regions of the thunderstorm and the dynamical movements in the clouds very often can give rise to such local concentrations of the charges as are necessary to explain the reaching of the disruptive limit of the air by very local field concentration regions.

2. DIMENSIONS OF THE FIELD REGIONS.

With regard to the lightning surges, it is of special interest to observe the dimensions of the charged volumes of the thunderstorm cloud. We can suppose that the thunderstorm cloud is composed of several small charge regions of different polarity, see Fig. 1*a*, or of greater regions of positive and

FIG. 1*a*.

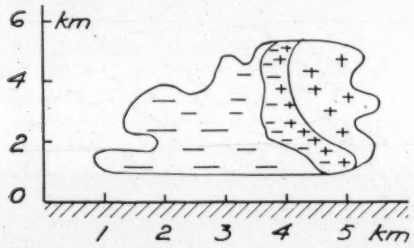


negative polarity, see Fig. 1*b*. Simultaneous records of the field on three or four stations[3] at different distances have

[3] H. Norinder, *Tekn. Tidskrift*, 53, p. 188, Stockholm, 1923.

led us to regard the form 1*b* as real. Charges of the same polarity are extended over considerable regions of the thunderstorm cloud. By the localizing of the discharge regions from

FIG. 1*b*.

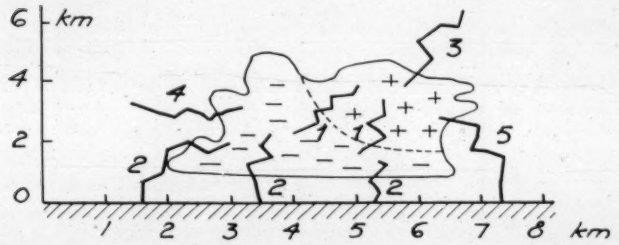


three different points on the earth's surface, it has been proved that the larger part of the discharges are developed within the internal parts of the thunderstorm atmosphere. Only a small part of the lightnings reach from the cloud to earth. The region of the main part of the lightnings is marked with the hatched surface in Fig. 1*b*. We must thus very often suppose localizations of high field force regions within the cloud. This concentration can be caused by several dynamical and ionic processes in the cloud.

A discharge sometimes goes from a cloud downward to earth without reaching it. Discharges may also be expected between the lower parts of the cloud and the earth. Very often the discharges go, as mentioned above, between the internal parts of the cloud. Sometimes discharges have also been observed from the top of a cloud upward into the higher parts of the atmosphere. Less frequently do the lightnings go either from earth to the cloud or in the opposite direction. These different lightning paths are marked in Fig. 2 by 1–5. Lightning surges on transmission lines are produced especially by the forms 1, 2, 4 and 5. By the forms 1 and 2, surges of positive polarity are caused. Sometimes a discharge can give a double polarity, as is shown in Fig. 3. In such a

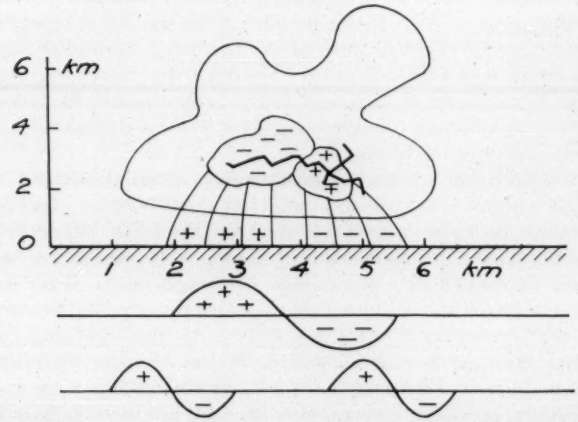
case, a part of the transmission line is exposed in a positive field and another part in a negative field, and both field

FIG. 2.



regions are changed and neutralized by lightning. The liberated charges in such a case go out on the line in the form of travelling waves.

FIG. 3.



From our own direct observations of lightnings, we have drawn the conclusion that the forms 1, 2 and 4 constitute the more frequent occurrence of lightning strokes. From direct

observations with klydonographs on lightning surges by J. H. Cox, McAuley and L. G. Huggins [4] the conclusion has been drawn that most surges are of positive polarity. This is explained in the following manner: The transmission line very often is exposed in a field of negative polarity. By the probable discharge directions in the cloud, a part of this negative field is neutralized and it thus results in a surge of positive polarity. It is obvious that most of the lightnings between clouds and the earth end with their positive end branches on the earth's surface. By lightnings to earth, cloud regions of negative polarity must be generally neutralized and thus positive surges preponderate on transmission lines.

3. THE REGIONS DISCHARGED BY LIGHTNINGS.

The dimensions of the regions in the thunderclouds that are discharged by lightning are of importance when estimating the primary, horizontal extension of the surges along transmission lines. If the regions discharged by lightnings should be of great extent in a thundercloud, we must postulate a small value of the field force in the cloud and vice versa. This can be easily verified by the calculating principles given above.

By simultaneous observations of the field changes on three or four stations, we have found a very pronounced limitation of the discharging regions. This is in full agreement with our researches on the electric field intensity in thunderstorms where we have found values ten times higher than the values assumed.

In order to get an estimate of the horizontal field variation from a discharging region, we can suppose the following: The concentrated charge may be within a small sphere and uniformly distributed. The charge thus can be considered as concentrated at a point—the center of the sphere, see Fig. 4. The charge Q is situated at the height h above the ground.

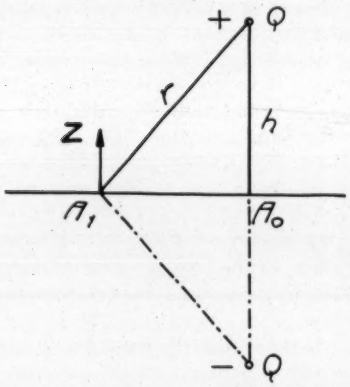
The field force dv/dz at a point A_1 can be calculated by

[4] J. H. Cox, P. H. McAuley, L. G. Huggins, *Journal A. I. E. E.*, pp. 459–467, 1927.

the relation

$$\frac{dv}{dz} = -\frac{2Qh}{r^3}, \tag{3}$$

FIG. 4.



and dv/dz is thus inversely proportional to the third power of the distance to the concentration point of the charge. When A_1 approaches A_0, r and h are approximately equal, and thus

$$\frac{dv}{dz} = -\frac{2Q}{h^2}. \tag{4}$$

Of special interest is the charge dq induced by Q on an element ds of the earth's surface. The relation is

$$dq = -\frac{Qh}{2\pi r^3} ds. \tag{5}$$

A transmission line near to the earth's surface can be considered approximately as a part of the earth's surface. The induced charge on a transmission line element may thus be approximately equal to the induced charge on a surface element ds multiplied with a constant α depending upon the characteristics of the line. The total charge Q can be defined

by the relation:

$$Q = -\alpha \frac{Qh}{2\pi} \int \frac{ds}{r^3}. \qquad (6)$$

When the discharging volume of a lightning stroke is considered to be concentrated upon a point, the induced charge on a line decreases very rapidly with the distance, as can be seen by the relation (6). Wilson [5] has calculated with a charge of 20 coulomb, a probable value of the charge in a lightning, to be concentrated at a point 1 or 2 km. above ground. The result of such a calculation is given in Table I.

TABLE I.

Distance from Concentration Point in Km.	Field Force in Kilovolts/Meters.	
	Height above Ground 1 Km.	Height above Ground 2 Km.
1 km.	152	78
2	28	28
3	11	16
4	7	12

The calculation of the field variation by the relations (3) and (4) is based on considering the charge as static. The influence of the rate of discharge is thus quite neglected. We have not in our hands any possibility to precalculate the rate of discharge when a flash of lightning is produced within a thundercloud, and it has thus been necessary to solve this problem in an experimental way.

4. A RESEARCH OF THE DISCHARGING RATE OF LIGHTNINGS.

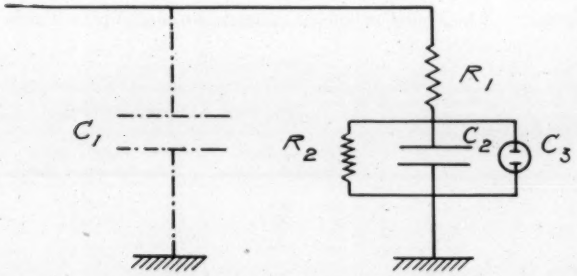
A lightning discharge produces an electromagnetic field to which the fundamental equations of Maxwell can be applied. It is thus possible to get the variations of this field on extended insulated surfaces or antenna wires. The characteristics of such systems must be suitably chosen only with regard to the discharging rate and the electrophysical char-

[5] C. T. R. Wilson, *Phil. Trans. of Roy. Soc.*, Ser. A, Vol. 221, pp. 73–115, London.

acter of lightnings. The aërial systems must be critically damped in order to avoid its free oscillations.

An aërial system used by the author consisted of an antenna 250 meters long at a height of 5 meters above ground. The aërial wire was connected above a condenser to a cathode ray oscillograph. A complete diagram of connections is shown in Fig. 5. The aërial system was connected to a

FIG. 5.



variable capacity C_2, which could be regulated to a maximum capacity equal to capacity C_1 of the aërial system. Parallel to this capacity was connected the small capacity C_3 of the deviation plates of the oscillograph. This capacity of the instrument could be neglected when making a comparison with the capacity of aërial system C_1, and the connection C_2. The aërial system was connected to C_2 through a damping resistance R_1 of 2,000 ohms to prevent free oscillations of the system. The capacity C_2 was closed to the earth by a resistance R_2 of 100,000 ohms or sometimes smaller values in order to avoid slow field variations independent of electrostatic fields.

We suppose the electric field force V produced by a lightning to follow the relation

$$V = f(t). \tag{7}$$

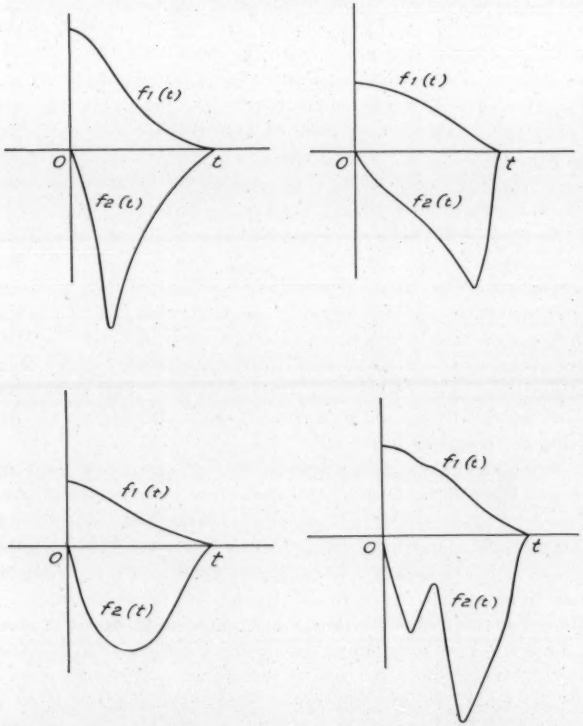
If thus the free oscillations of the aërial system are suppressed,

its charge Q must follow the differential equation:

$$L\frac{d^2Q}{dt^2} + R\frac{dQ}{dt} + \frac{Q}{C} = f(t). \qquad (8)$$

The first term can be neglected because the value of L is

FIG. 6.



small in the system. A solution of (8) shows[6] that the

[6] R. A. W. Watt, E. V. Appleton, "On the Nature of Atmospherics," *Proc. Roy. Soc.*, Ser. A, Vol. 103, A. 720, London, 1923.

voltage variation V above C_2 and C_3 follows the relation:

$$V = \frac{C_1}{C_1 + C_2} f(t). \tag{9}$$

The relation (9) can be valid if $f(t)$ is an exponential function or a sinusoidal one or a combination of the two. Also if $f(t)$ is changing in a linear way, the relation (9) is valid. It is necessary only to have a small value of the time constant of the system in comparison with the duration of the lightning impulse of the aërial system. We suppose the discharge variation of a lightning to be represented by a function $f_1(t)$. The corresponding variation of the voltage on the aërial system easily can be estimated. This is shown in some examples, Fig. 6, where $f_2(t)$ represents the voltage variation above C_2, caused by $f_1(t)$.

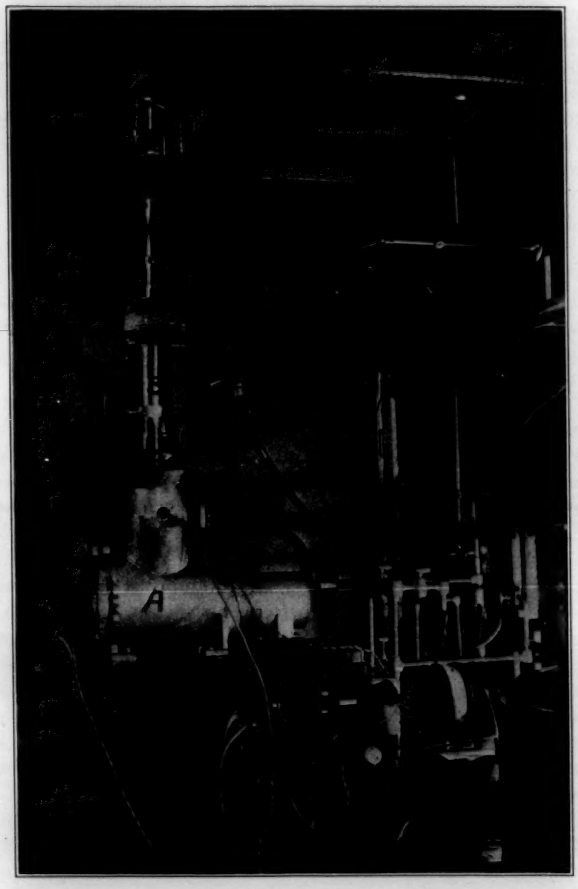
By the aërial system mentioned above and a cathode ray oscillograph, it has by our methods been possible to record lightnings. The first researches,[7, 8] executed by a Braun tube used as an oscillograph, showed that the lightning flashes were unidirectional and often slow in their variation characteristics. Some of the lightnings showed a very short period of growth to their maximum value. The time sensitivity of the Braun tube prevented, in such cases, a definite fixing of the growth period.

For the thunderstorm season of 1927, we have built up, at the Uppsala experimental station of the Swedish Royal Board of Waterfalls, a specially constructed cathode ray oscillograph. In this instrument, the film was situated within the evacuated vessel; it is thus possible to record time variations of an order of magnitude of microseconds. A general view of the specially constructed instrument is given in Fig. 7. This instrument has a characteristic feature which renders it possible to record phenomena of a duration a million times shorter than its total and effective time of exposure. This is realized by the application of a special device that causes the electron jet itself to act as a relay.

[7] H. Norinder, *Teknisk Tidskrift*, 53, 10, 1923.

[8] H. Norinder, *Teknisk Tidskrift*, 55, 8, 1925, Stockholm.

FIG. 7.



The new type cathode ray oscillograph for recording lightning discharges.

The electron jet thus records only when a suitable voltage or a current is applied to the deviation equipment. The instrument is thus independent of the time of arrival of a phenomenon that should be recorded. It was only by this property of the instrument that it was possible to record lightning from thunderstorms where it was quite impossible to predict and control the arrival of the lightning. As the cathode oscillograph allowed a time of exposure of an hour or more, it was readily possible also for us to record a number of lightning voltages in a locality where the frequency of thunderstorms and the lightning strokes in them was very low.

Our earlier results of lightnings were generally verified by the records of the sensitive cathode oscillograph. Besides the lightnings of a slow variation type, we observed lightnings showing an extremely short growth period. It is just these lightnings that are of special interest with regard to lightning surges on transmission lines.

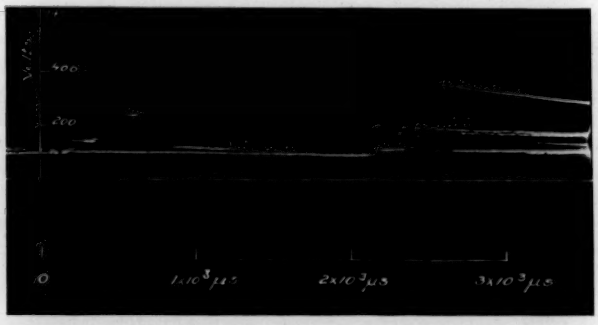
The lightning was found to be without exception non-oscillatory. Sometimes we observed a superimposed high frequency of an amplitude of only a few per cent. of the total field variation, due to lightning. The occurrence of this high frequency was a very irregular one. Until the present time, we have not obtained sufficient observation material to be able to give a physical explanation of the superimposed and irregular high frequency. By simultaneous observations of the occurrence of the high frequency in the oscillograph, and the atmospheric disturbances in a radio receiver, we have found that the main part of the statics in a thunderstorm at some distance from the locality of observation is due to this superimposed high frequency. Its periods have been estimated to vary between ten and thirty microseconds. This explains why a radio receiver for ordinary wave-length can be disturbed.

For distant lightning strokes, our time constant has been of the order of one microsecond and this may be neglected in view of the total duration of the lightnings. Lightning discharges, produced within a few kilometers from the obser-

vation point, were very often followed by a persistent field change independent of the time. This necessitated a reduction of the effective leakage of the system and thus of the time constant.

In Fig. 8 is shown a direct reproduction of a lightning

FIG. 8.



First records of lightning discharge in an antenna.

record taken with the oscillograph. The lightning in this record has a growth period of 1.2×10^3 microseconds. This slow growth period cannot produce any surges on a trans-

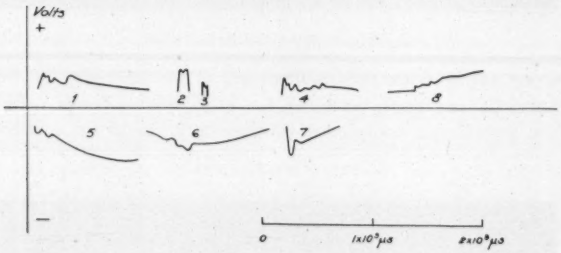
FIG. 9.

First records of lightning discharge in an antenna.

mission line. The charge will have time enough in this case to spread out over the line. In Fig. 9 are shown direct reproductions of two other lightning types with rapid growth periods. The voltage of these lightnings has surpassed the recording limit of the instrument. If we consider the changing conditions of the field variations of lightnings, such a passing of the recording limit is sometimes inevitable. By the regular variation in the records, we have found it possible to approximate the point of reaching maximum voltage in the records. This top voltage is reached within 125 to 150 microseconds. About 30 per cent. of the change of field in its building-up period has passed in a few microseconds. It is obvious that lightning, where the field has its main variation in so short a time as a few microseconds, must cause indirect surges on transmission lines.

To illustrate this: some of the most rapid lightning records have been reproduced in Figs. 10 and 11. The types

FIG. 10.



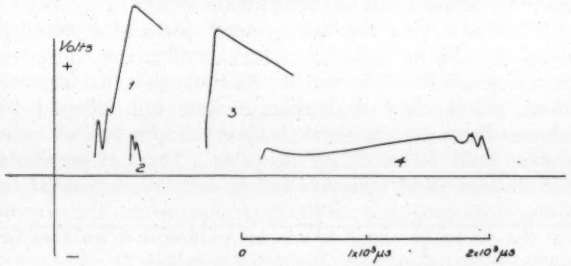
of lightning in Fig. 10 that may produce surges are Nos. 1, 2, 3, 4, and 7. The slope ratio in Nos. 5, 6, and 8 will not produce transmission surges. In Fig. 11, Nos. 1, 2, and 3, we have a short building-up period which is necessary to cause surges.

It may be observed that our voltage scale is relative. For practical reasons, we have not found it necessary to establish an absolute voltage scale in this preliminary research

where the main interest was to solve the problem of the discharging characters of lightning.

With regard to their initial and ending conducting regions, two main forms of discharges are possible: (*a*) Those between different charged parts of the thundercloud. (*b*) Those from earth to a charged part of the cloud where only one part of

FIG. 11.



the discharging region, the cloud, can be considered as a semiconductor, while the other part, the earth's surface, must be considered as a perfect conductor.

From the researches of B. Walter [9] who has photographed the lightning with the aid of a rotating camera, it may be concluded that the lightning sometimes grows from region to region in the atmosphere. The disruptive discharge in form of a lightning is thus preceded by an extended ionization process. The resistance of the discharge region becomes in such a case sometimes of such high value that a lightning which has been developed along a part of a discharging path ceases. A ceasing of an initiated discharge process must especially be possible if the two discharging regions are both within the thunderstorm cloud. Their property of being semiconductors limits the flow of electricity within them.

We had, during our seasons of thunderstorms, many opportunities to observe visually, by the aid of a cathode

[9] B. Walter, Jahrbuch der Hamburgischen Wissenschaftliche Anstalten, XXI, Hamburg, 1904.

oscillograph, such slow-moving processes as those which initiate lightning.

The discharging process is developed in somewhat another way, if we regard the discharge between earth and a cloud. In this case, we have the main resistance in the cloud. When the discharged path is developed, there is sometimes reason to suppose a disruptive and fast discharging process of the lightning for some part of the lightning path.

When observing the more central parts of a thunderstorm, the electron jet of a cathode oscillograph connected to an antenna circuit indicated sometimes slow-moving variations. These slow field changes were not followed by ordinary lightnings, as could be observed by a special radio receiver built for recording lightning. There is no doubt that the slow field variation was in such a case caused by slowly developing glow discharge regions where the current into the discharge channels was not sufficient to go over to, and to cause, an ordinary disruptive lightning.

As mentioned above, we have found two different discharging types of lightning, one of which is of a very slowly moving character. There is no doubt that these slow discharging processes are caused mainly by discharging processes between internal cloud parts of the thundercloud. The rapid discharging lightning, on the other hand, may be caused by discharges from some part of a cloud to earth or from earth to the cloud. But it seems possible that there are some exceptions to this general rule. The conditions within a thunderstorm cloud are so irregular and unstable that it is probable that sometimes rapid lightning may also be developed within the cloud itself. This may especially be the case for secondary lightning that is initiated in the ionization processes of primary slowly moving lightnings.

From our researches on the discharging nature of lightnings, we can draw some general conclusions with regard to lightning surges on transmission lines. There are three principally different forms of such surges to be expected on the lines: (1) Indirect lightning surges, where no stroke has

gone to the line. (2) Direct lightning surges, where a stroke has gone from, or to, the line. (3) A combination of the two forms (1) and (2).

The indirect lightning surges must very often have their fronts slightly sloping. We may suppose from the discharging character of lightning that the maximum field strength in the building-up period is reached within a few to a hundred microseconds. On the other hand, the direct lightning surges sometimes must have very straight fronts where the maximum field force is reached within a few microseconds. The line can, in such cases, be suddenly charged from a part of the ionized lightning path and thereby fronts are produced where the peak voltage can be reached within a microsecond.

With regard to their polarity, we can conclude, both from direct observations and from theoretical reasons, that positive surges are the more frequent.

Direct Evidence of Atom Building. R. A. MILLIKAN AND G. H. CAMERON. (*Science*, April 13, '28.) Millikan and his coadjutors have studied the penetration of the cosmic rays into the waters of mountain lakes in California and Bolivia and, in the opposite direction, have obtained registration of their effects by sending self-recording electrometers up on sounding balloons to such an elevation that nine-tenths of the earth's atmosphere lay beneath. Such investigations made during the last year show that the cosmic rays consist of wave-lengths occurring in bands of definite frequency and, therefore, do not cover continuously long stretches of the spectrum. The frequencies of the rays are 100,000,000,000 times as large as those of the radiation from a neon lamp or a Cooper-Hewitt mercury arc lamp. This difference accounts for their great penetrating power.

In the spectrum of the rays there are four chief regions found in a range of three octaves, and all of the four can be accounted for according to Einstein's equation as emitted upon the combination of positive electrons, that is, of hydrogen nuclei or protons, with negative electrons to form the atoms of light elements. The most prominent band in the spectrum is due to the union of four protons with four electrons to make an atom of helium. This is accompanied by a loss of mass which goes off in the form of energy in an ether wave having a calculated coefficient of absorption that agrees within a few per cent. of the coefficient actually observed. The formation of oxygen and nitrogen from hydrogen causes the second spectral region, the creation of silicon and magnesium accounts for the third and the making of the iron atom for the fourth.

For some decades it has been known that "heavier atoms are disintegrating into lighter ones," but evidence has been wanting of the inverse constructive process. "The present experiments constitute the first discovery of such evidence. It must be taken with some reserve and must be subjected to further critical analysis and further experimental tests. But, as far as they go, these experiments are at least indications, and the first direct indications, that all about us, either in the stars, the nebulæ or in the depths of space, the creative process is going on, and that the cosmic rays that have been studied for the past few years constitute the announcements broadcast through the heavens of the birth of the ordinary elements out of positive and negative electrons. If it is confirmed it will constitute new proof that this is a changing, dynamic and continuously evolving world instead of a static or merely disintegrating one."

G. F. S.

REPORT ON THE WORK OF THE BARTOL FOUNDATION.*

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W. F. G. SWANN, D.Sc., Director.

INTRODUCTION

THERE was a time when the interests of the man of science embraced all nature and when his contact with human affairs was made chiefly through a profound belief of all men in his supposed infinite capacity for wickedness. Great learning was symbolic of the knowledge of many facts, and the philosopher's prestige was measured by the weight of his manuscripts. And then the sciences divided themselves. The chemist went one way, the natural philosopher another, and the biologist another. Moreover, the chemist segregated his family into groups and there arose the inorganic chemist, the organic chemist and the physical chemist. The natural philosophers divided themselves into experimental physicists and so-called applied mathematicians, so that the other kind of mathematician called himself a pure mathematician, thereby dissociating himself from the intellectually immoral applied mathematician who differentiated things without knowing whether they ought to be differentiated, who sought solutions of equations which might not have any solutions, who expanded functions in series without knowing whether the series meant anything but who, in spite of his wickednesses, was usually guided by some kind providence so that his conclusions were aggravatingly often correct. Then the experimental physicist divided his family into pure physicists and engineers, and each sought to work in his own sphere. I once knew an institution in which on adjacent floors were two departments, one for physical chemistry and the other for chemical physics; someone once asked me what the difference was, and all I could think to say was that there was more physics in physical chemistry than there was chemistry in chemical physics.

* Presented at a meeting held Thursday, March 15, 1928.

As the separate groups continued to burrow for the truth in their water-tight compartments (or perhaps we might say thought-tight compartments) it began to appear that somehow or other they must come together again. For when the superficialities of the special fields became exhausted it was necessary to appeal to the fundamentals of the sciences and these were the same for all.

The physicist now bases his views of the atom on theories of the pure mathematician which he formerly regarded as in the forefront of practical uselessness. The chemist finds it necessary to inquire as to the detailed nature of the mechanism of the atom which the physicist has ferreted out, for only by a consideration from this aspect can he satisfactorily control such things as catalytic action and the like, which have now become of importance to him. The engineer can no longer content himself with the former rules of engineering practice; for, the devices which he has come to use, the radio tube, the electron rectifier, and many others, draw more and more upon the properties of those fundamentals of the fine-grained structure of nature whose elucidation is the problem of modern physics. Even the biologist has exhausted the possibilities of the superficialities of his science, and his further progress depends upon the more minute study of atomic processes, of colloidal behavior, and of the minute structure of matter as revealed by X-rays.

One of the most astonishing things in nature lies in her possibilities to conceal phenomena of transcendent moment until their secrets are wrested from her by force. When we contemplate all the manifestations of electric power today we wonder why it was that in the millions of years of her life nature did not in some part of the universe, and of her own accord, throw together such a machine as a dynamo for the accomplishment of some gigantic purpose. Why is the principle of the radio amplifier tube not employed spontaneously somewhere? Why are not X-rays, with their enormous potentialities, used by nature herself on a large scale? It is almost as though it were the plan of the Grand Architect of the universe to leave the structure unfinished that the completion thereof might form a stimulus and a delight to man.

Discoveries in the past were made largely by trying things

without very much idea as to what would happen. Nearly all the developments of the present time follow, however, from a more detailed knowledge of the nature and behavior of such things as atoms, molecules, electrons, X-rays, etc.; and it is largely as the result of our enhanced understanding of fundamental processes that the progress of the last twenty years has been as great as it has.

And so it is with the nature of fundamental processes that the physicist or the chemist devotes himself most intensively at the present time. Thirty years ago he would have been vitally interested in how most accurately to measure the electrical conductivities of wires and of solutions, and how to determine most certainly their variations with temperature. Now he is more vitally interested in the detailed mechanism of the conduction process itself. Thirty years ago he spent much time in recording the spectra of gases, for it then seemed hopeless to understand them. Now he feels that he has gone a long way towards such understanding and this greater light has suggested many new possibilities and has increased his power to surmise what may be possible in controlling the actions of matter and what may not.

It is not a very easy matter to describe in a short time all of the investigations which are at present under way at the Bartol Research Foundation. It will be necessary to omit much which pertains to the details of the experimental procedure and concentrate upon the main features and upon the natures of the problems themselves.

THE EMISSION OF ELECTRONS FROM WIRES UNDER THE INFLUENCE OF THE INTENSE ELECTRIC FIELDS

An important problem having to do with the way in which electricity is bound to matter is one which is being carried out by Mr. del Rosario.

I must remind you that we believe the power possessed by metals to conduct electricity finds its origin in the presence of free electrons in the metals. It may seem strange that we speak of things which can move freely in the solid substance of a metal. But we must remember that just as a room piled to the ceiling with chairs may be very full as regards the passage of a human being, and yet very empty from the

point of view of a fly, so the atoms which are clustered so thickly together for one who views them with our coarse-grained eye are, to things much smaller, as full of emptiness as our solar system is empty of planets. If I could squeeze out all the nothingness that is within me, I should be much smaller than a flee, even though I should carry as much weight as before. As there is plenty of room for a comet to wander freely in our solar system, so, for an electron whose size compared with that of the atom is like that of a fly in comparison with that of a cathedral, there is plenty of room to wander about in the sparsely occupied spaces between the atoms.

These free electrons are responsible for many things. They carry the electric current through the wire. They are in a state of rapid motion like the molecules of a gas; when the temperature of the metal is raised, that motion is increased. We might suppose that, owing to the motion, some of the electrons would fly out of the metal and escape. As a matter of fact, this does happen, but only to an extremely small extent at ordinary temperatures; for directly the electron starts to get away it is pulled back by its attraction for the metal which it is leaving, or rather by the reciprocal reaction resulting from that attraction. A certain minimum velocity is necessary to enable the electron to escape, and even at temperatures which would melt the metal only a very small proportion of the free electrons possess the necessary velocity.

If we imagine an electron starting out of the metal and then falling back by the attraction to which I have referred, we may plot a curve giving the energy it would have to attain to get to various distances from the metal. We might imagine curve 1, Fig. 1, to represent such a curve. Thus, if the electron is to get to the point A, it must start off with a kinetic energy equal to AB. If it is to get clear away, it must have the initial energy CD. In practice, the energy CD corresponds to the energy gained by an electron in falling through a potential difference of about 4 volts.

Suppose we charge the surface negatively, or bring a conducting plate near to it and set up a difference of potential between the plate and surface in such a way that the surface is negatively charged. Suppose, in fact, we create in the

vicinity of the surface an electric field E which is in such a direction as to urge the electrons away from the metal. Then curve 1 will become modified, because the energy necessary to enable an electron to get to any point along the line OP will be reduced by just the amount of work which would be done on the electron by the field in taking it to that point. Our curve 1 will be changed to such a curve as 2,

FIG. 1.

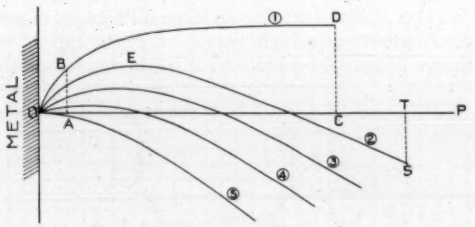


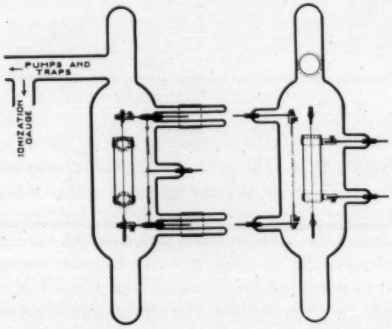
Fig. 1. Now, considering this curve, if the electron could go from O to T, it would not, on the whole, lose any energy at all, but would, as a matter of fact, gain energy equal in amount to TS. It is no consolation for the electron to know this, however, if it cannot get over the hill at E. The electron has no credit by which it can borrow energy. It is in the position of a man who faces a very steep hill on a bicycle but is unable to ride up on the mere stimulus provided by knowledge of the fact that the bottom of the hill on the other side is lower than the place where he now is. As we increase the electric field, however, the hump at E becomes ironed out more and more, as shown in curves (2 and 3 and 4), until finally when the field is sufficiently great as at curve 5 it is ironed out completely. Until this condition is reached very few electrons will be able to escape from the wire, but as soon as this condition is attained there will be nothing to prevent a huge efflux of electrons.

The slope of curve 1 as calculated from the attraction of the electron for its electrical image amounts to about 3×10^8 volts per centimeter at a distance of about 10^{-8} cm. from the surface. The slope increases as we approach the surface, and

would become infinite there if that surface could be treated as a completely homogeneous conducting surface. The fact that the surface is not homogeneous but is broken up into atoms and molecules prevents a realization of this infinite surface gradient, but a consideration of the conditions suggests that the gradient would certainly be of the order of 10^8 volts per centimeter, so that to wipe out the hump at E we should expect that fields of the order of 10^8 volts per centimeter would be necessary.

Now, as a result of setting up large differences of potential between conductors in high vacua, currents appear to have been drawn from cold metals with fields much smaller than

FIG. 2.

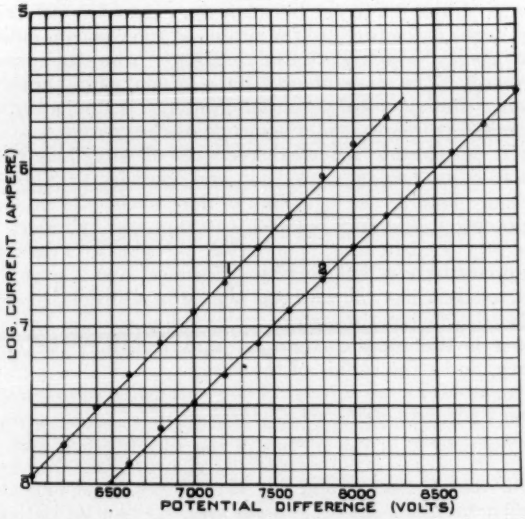


10^8 volts per centimeter; and, as a matter of fact, an X-ray tube depending on this principle was invented some years ago. Quite apart from its immediate practical bearing, however, the investigation of these phenomena, which control the bonds which hold electrons in matter, is of the utmost interest from the theoretical point of view, for these surface forces play a part in the operation of most modern electrical devices, the Coolidge X-ray tube, the vacuum tube of radio, the vacuum tube rectifier, the photo-electric cell and so forth.

One method of getting a large electric field at the surface of a conductor without invoking excessively high differences of potential between electrodes is to use a fine wire surrounded

by a coaxial cylinder. For an assigned difference of potential between the wire and cylinder, the field at the surface of the wire may be increased without limit by diminishing the diameter of the wire. Experiments with apparatus of this kind have been performed by Millikan and Eyring, who came to the conclusion that electrons could be drawn from cold electrodes in vacuum with a field of the order of 350,000 volts

FIG. 3.



per centimeter. Mr. del Rosario has carried out experiments of this kind at the Bartol Foundation but has extended the measurements to wires of various sizes. The use of different sized wires enabled him to produce different surface fields for the same differences of potential, or different differences of potential for the same surface field, and so ascertain whether the current really depended primarily upon the field at the surface of the wire or upon the total difference of potential existing between the wire and cylinder. If the same surface

field always produces the same current density regardless of the size of the wire, we may feel a certain amount of confidence that the current arises by the action of the field in pulling electrons out of the metal. On the other hand, if the current density associated with a certain field depends upon the size of the wire, we may have doubts as to the fundamentality of the pull of the field as the primary origin of the phenomenon. More particularly, if, regardless of the size of the electrodes, the thing which determines the total current from the wire is the potential difference between the electrodes, we immediately begin to picture, as the origin of the electron emission, some agency which derives its energy from the potential difference. The experiments have given quite conclusive evidence that the total potential difference is the factor which determines primarily the magnitude of the current.

Mr. del Rosario has used five sizes of wire, four ranging from 16×10^{-4} to 53×10^{-4} cm. and one wire 12×10^{-3} cm.

Figure 3 shows the logarithm of the current plotted against the potential difference between the wire and cylinder. The curve is a straight line; Curve No. 1 refers to a case where the apparatus was baked with a furnace, and Curve No. 2 refers to one where the wire was heated in addition by sending an electric current through it.

If I is the total current per unit length, i the current density, and r the radius of the wire,

$$I = 2\pi r i. \tag{1}$$

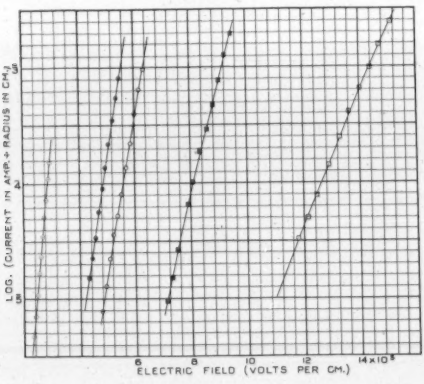
Now the field X at the surface of the wire is given by

$$E = \frac{V}{r \log b/r},$$

where V is the potential difference between the wire and cylinder and b is the radius of the cylinder. If i is a function of E only, then in plotting $\log I/2\pi r$, which is $\log i$, against $V/r \log b/r$, which is E, we should obtain a curve which is the same for all wires. When we do this, however, we obtain five different curves, one for each of the five wires, as shown in Fig. 4, where the curve for the largest wire is to the extreme left and that for the smallest to the extreme

right. On the other hand, if we plot the total current I against the potential difference, all the points, at least for the four wires ranging from 16×10^{-4} cm. to 53×10^{-4} cm., fall on the same curve. The results are shown in Fig. 5, where the points for the different wires are represented by different symbols. The five symbols in a verticle line to the left of the graph indicate from top to bottom the order of the

FIG. 4.



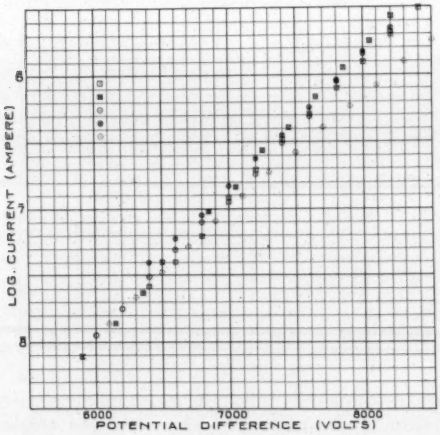
thicknesses to which they refer, the top symbol referring to the thinnest wire. The points for the fifth and thickest wire fall off the curve, for a reason which is to be expected and which will subsequently be discussed.

It will be observed that the points for the four different wires fall as well on one curve as do the different points for a single wire. These data seem to indicate, therefore, that —at any rate in the present experiments—the thing which is operative in determining the discharge is the total potential difference between the electrodes, and the situation is not one where we have a phenomenon determined entirely by the creation of a current density by a field at the surface of the wire.

Of course, there are many details which one familiar with this kind of work would naturally wish to inquire into. Thus,

for example, the vacuum attained in the apparatus is of the order of 10^{-8} mm. It is so high that only one in every hundred thousand millions of the molecules at atmospheric pressure remains. In order to obtain this degree of vacuum very great precautions are necessary, all of the metals must be handled by gloves so as to avoid contamination by the fingers, the apparatus must be baked out in a very careful

FIG. 5.

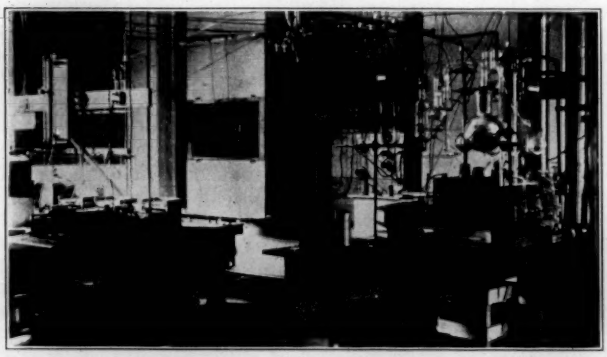


and elaborate manner, the details of which would take me a long time to describe. I need only to remark that in comparing wires of different sizes the heat treatment given was, as far as possible, the same in each case.

We could explain the general nature of Mr. del Rosario's results if we could assume that the cylinder emits or is caused to emit positive ions which then travel to the wire gaining energy proportional to the difference of potential, and if we could further assume that, as a result of this, the positive ions raise the temperature of the wire in the extreme local regions where they hit so that electrons are given off by thermionic emission. We might suppose that the average

temperature of a spot hit by a positive ion would be proportional to the energy of that ion, and so to the potential difference. Under these conditions the emission of the electron would be such as to cause the current potential curve to be of the well-known exponential form and correspond to a linear relation between the log. of the current and the reciprocal of V, so that for smaller ranges of V there would be the linear relation between the log. of the current and V

FIG. 6.



itself just as in the case of thermionic conditions there is a linear relation between the log. of the current and temperature for small ranges in temperature. Another point in favor of this view arises from the following facts. If the potential difference be increased beyond the range used in any series of observations, the log. current-potential curve will not retrace itself on diminution of potential but will assume a position shifted towards the higher potentials. It will then stay steady for variations of potential back and forth over the new range. Now the shift of the curve toward the higher potential is exactly the phenomenon produced by more prolonged baking of the wire, and we may well suppose that the effect of the bombardment of the positive ions is to bake the wire, not all over at once so that it becomes visibly hot,

but in isolated spots at a time in such a manner that, after a time comparable for example with one second, the whole of the surface of the wire has experienced a rise of temperature to the value corresponding to the energy of the positive ions.

We know that alpha particles, when impinging on a metal, release only about 10 electrons per alpha particle, so that it might appear that in order to account for the electron emission by the positive ions a larger positive ion current would be necessary than it is practicable to assume. It is not improbable, however, that the conditions of release of electrons by bombardment of positive ions under the influence of high electric fields such as we have at the surface of the wire may be quite different from those attending their release in the absence of a field or with a very small field. In fact, it may be that we are confronted with a space charge phenomenon in the case of the emission and that a fairly large field intensity is necessary to insure the emission of the maximum current even though that current may be independent of the field intensity, provided that the latter is large enough. If this were the case, we should expect that for very large wires the points on the log. current-potential curves would fail to fall on the same curves as those for small wires, since for these large wires the field would be insufficient to insure saturation. It may be for this reason that the points for the largest wire in Fig. 5 fall off the main curve corresponding to the other four wires. The departure is in the right direction to correspond to the foregoing views. It is further possible that positive ion emission from the cylinder may be brought about by the electron bombardment, although if this were the case it would not be in harmony with the facts to assume that emission is proportional to the electron current itself, for it is easy to see that under these conditions the current would mount up immediately to a state of instability and would in fact become infinite. If the electron current functions at all in promoting the emission of positive ions, it must do so in some manner which leaves to the cylinder itself the decision of the number of ions that shall be emitted per sec., as would be the case, for example, if that emission were determined by the rate of diffusion of the ions from the inner parts of the cylinder to the surface,

their subsequent emission being promoted by the bombardment of the electrons. However this may be, the next plan is to carry out these experiments with cylinders and wires of different materials.

The thought was that X-rays emitted by the cylinder as a result of the bombardment of the electrons might play a part in maintaining the current. On such a view one would again expect a condition of instability of current to arise if the current could be maintained at all by this process. However, Mr. del Rosario has certain experiments in progress to test this matter.

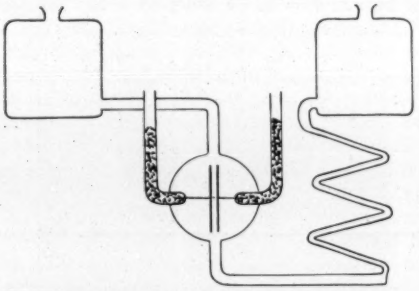
THE ELECTRICAL CONDUCTIVITIES OF NON-AQUEOUS SOLUTIONS.

An important field of modern physics is that concerned with understanding the processes which determine the conduction of electricity through solutions of salts. Very briefly we may say that the fundamental concept is that molecules of salt when dissolved split up into positive and negative ions and these move in opposite directions under the influence of the electric field. The problem is to calculate the conductivity of the solution as a function of various elements which enter to control it. The problem is of course a very old one but it is only within recent years that our familiarity with the whole situation has enabled it to be attacked in any detail. The conductivity of a solution would be given by $N_1E_1V_1 + N_2E_2V_2$, where N_1,E_1,V_1, refer respectively to the number per c.c., the charge, and the mobility for one kind of ion and the letters with subscript 2 refer to the other kind of ion, the mobility being understood as the velocity of the ion under unit electric field. Now, according to the simplest view, we may suppose the velocity to be simply proportional to the field, and in this case if N_1 and N_2 are both proportional to the number of dissolved molecules then the molecular conductivity, i.e., the conductivity divided by the number of dissolved molecules per c.c., should be a constant. Experiments very soon show that such a result is not in harmony with the facts, but it was not until about 1923 that Debye and Onsager examined sufficiently closely the elements which enter into the determination of mobility to derive some theoretical reason for the fact that the molecular conductivity

depends on the concentration even for diluent solutions. The elements which determine the mobility are many and complicated in nature. First we have the external electric field itself; then, any one ion tends to cluster around itself the ions of opposite sign and these tend to shield that ion from the electric field. Again, the viscosity of the solution plays a part in determining the mobility of the ion, but not in a very simple manner because the ions of opposite sign clustering around the particular ion under consideration move in a direction opposite to it itself and so increase the relative velocity between it and the fluid. Then the temperature of the liquid plays a part not only in determining the viscosity but in modifying the results of the mutual attractions of the ions. It would take far too much time for me to go into this matter in such detail as to indicate how Debye and Onsager arrived at an expression for the molecular conductivity as a function of these various considerations. It will suffice to say that they did obtain such an expression which, if it is correct, enables us to calculate the actual magnitude of the molecular conductivity as a function of known constants of the solvent and of the molecules dissolved —constants such as the viscosity, the dielectric constant of the medium, etc. An experimental verification of these conclusions is of the greatest importance since if they are confirmed, our confidence that we have formed the right picture of the mechanism of conduction is strengthened; while if they are not confirmed, we know that we must seek still further for a proper interpretation of that which happens. Experiments on aqueous solutions have already been made and in a general way confirm the conclusions of Onsager. However, owing to the very large dielectric constant of water it turns out that some of the factors which play a part, and particularly the influence of the electric forces, due to the ions on each other, are very much reduced for aqueous solutions so that the experiments do not constitute a very complete test of the theory as regards these features. For these reasons Dr. O. E. Frivold, who came to us from Norway, has been engaged on measurements of conductivity in non-aqueous solutions. I will not enter into any very great detail in describing the fine points of the experiments which Dr.

Frivold has carried out. He will, of course, publish these in detail at a later date. The little spherical cell Fig. 7 contains between its two plates the solution to be tested. It turns out that the very greatest precautions are necessary in respect to freedom from moisture and other impurities to secure results of a desired accuracy, and for this reason it is not desirable

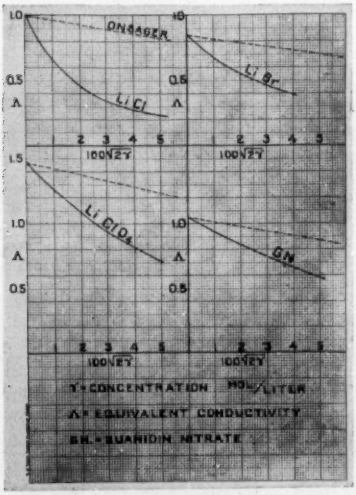
Fig. 7



to leave the liquid in the vessel while being tested since it is apt to become contaminated by the metal plates. The procedure adopted was to allow the liquid to flow both backwards and forwards through this vessel during the measurements and in this way any alterations of the constants of the liquid as a result of the metal plates or of the actual measurements were shared by the whole quantity of liquid used rather than by the very small amount contained within the cell itself. It was, of course, necessary to measure the conductivity of the salt (in this case cyclohexanol) so that it could be used in connection with the conductivity of the solution as a whole to determine the conductivity contributed by the dissolved salt. The salts which were used in the investigation were lithium chloride, lithium bromide, lithium chlorate, guaniodine nitrate. The preliminary results are shown in Fig. 8. Molecular conductivity is plotted against the square root of the concentration. According to the very simplest of our theories the conductivity would, as I have said, be independent of the concentration so that the curves would be straight lines

parallel to the horizontal axis. According to the theory of Onsager the curve for dilute solutions should be a straight line inclined to the angle shown in the figure. The lower curve represents in each case the actual results obtained by Dr. Frivold. No very great significance must be attached to the fact that the lines are not straight for higher concen-

Fig. 8



tration since the theories of Debye and Onsager apply only to dilute solutions. As a matter of fact the departure from linearity is in the direction which would be in accordance with the theory. In discussing the bearing of the results on these theories we are concerned with the initial slopes of Dr. Frivold's curves. These slopes indicate in a general way that the effect of the interionic forces is about twice as great as that required by the theory of Onsager. The experimental investigations have only just been completed and so the problem is now at a stage where we must seek for a further modification of the theory in order to account for these data.

THE EXCITATION OF SPECTRA IN MERCURY VAPOR BY ELECTRON IMPACT

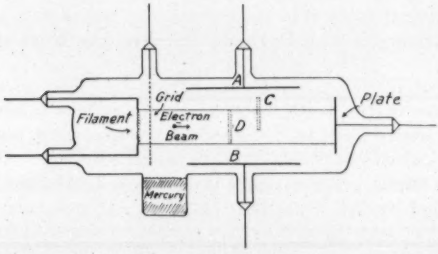
One of the most fruitful fields of research for the elucidation of information on atomic processes is the so-called spectroscopic field. I must remind you that if light coming from a glowing gas be allowed to fall on a slit which is placed at a great distance from a triangular block of glass, or if the optical arrangements are made such that the light comes to the triangular block of glass as though it had come from the distant slit, then, after passing through the triangular block the light becomes split up into beams in various directions, and if these are received by a suitably focussed telescope they appear as distinct lines separated from each other by definite angular amounts characteristic of the gas. We believe that each of these lines is characteristic of a type of vibration going on in the atom of the gas which emits the light.

I must further remind you that, at any rate according to our views in the immediate past, an atom is a little solar system with electrons rotating about a central nucleus in definite orbits as planets rotate about the sun. We have come to think, however, that under these conditions no light is radiated by the atom, but that if an electron falls from an outer orbit to an inner one, then light is produced of frequency depending upon the change of energy which the electron experiences in the fall. In general, the electrons of an atom are in stable orbits from which they do not tend to experience any falls of this kind, but by various means we may hurl some of them into outer orbits from which they have a chance to fall back to the places from which they came, and in this way we may cause them to emit light. We believe that the light obtained in the electric arc, for example, is produced in this way. By a more violent action, we may hurl electrons right out of the atoms, leaving them postively charged, and again the light will be produced by the return of the electrons to their former orbits. The light produced in this way is characteristic of the electric spark where the agency for hurling the electrons out of the atom is, on account of the greater electric fields, more drastic than it is in the case of the arc. We see, therefore, that the primary difference between that light which we think of as characteristic of the spectrum of

the spark and that which is characteristic of the spectrum of the arc, is that in the former case we think of the electrons falling into a charged atom in the production of light while in the latter case, they simply fall from one place to another in the neutral atom.

We have come to speak of lines other than those actually produced in an arc or in a spark as arc lines or spark lines accordingly as we believe them to originate in one of these types of process or in the other. Now, in order to illustrate the significance of one of the matters which Dr. Maxwell is investigating, I will ask you to think of a beam of electrons

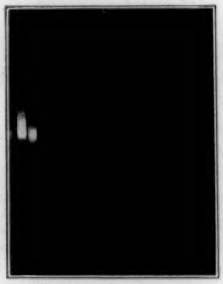
FIG. 9.



passing through a tube containing mercury vapor as shown in Fig. 9. Suppose that we examine the spectrum produced and suppose that some of the spectrum lines which we get as a result of the action of this beam in hurling the electrons about in the atoms are of the arc type and some of the spark type. Let us first concentrate our attention upon the arc line. The electron is moved from its stable orbit to some other and falls back again emitting light. During the whole of this time the atom is neutral. If, therefore, we should produce an electric field between the plates *A* and *B* and in a direction parallel to the slit of the spectroscope it would have no effect whatever upon the phenomenon. Suppose, however, that the light were produced by the spark process; then an atom for example, at the lower edge of this beam would have an electron hurled from it and it would immediately start to move upwards under the influence of

the electric field between the plates *A* and *B*. Unless the electron which was hurled from the atom or some other electron fell back immediately it would have moved some distance upwards before it succeeded in emitting any light. The result of this would be that on examining the lines of the spectrum we should find that such a spark line would be displaced upwards as indicated by *C*, as compared with an arc line which would be undisplaced. You will therefore see that experiments of this kind enable us not only to find out which are the arc lines and which the spark lines, but they give information as to the time which an atom can remain in the

FIG. 10.



charged state without being neutralized once more by the emission of light as the result of the acquirement of an electron.

Fig. 10 shows the result of actual experiments of this kind. The line farthest from the edge of the picture is an arc line. The other is a spark line. In the absence of the cross field, the two lines were practically alike. The cross field while leaving the arc line unaffected has produced a marked displacement in the density distribution of the spark line.

A more detailed consideration of this situation shows that we may extract other kinds of information from experiments of this nature. Thus for example, suppose some of the atoms experience as a result of the electron beam a two-fold catastrophe—an electron is hurled completely outside and

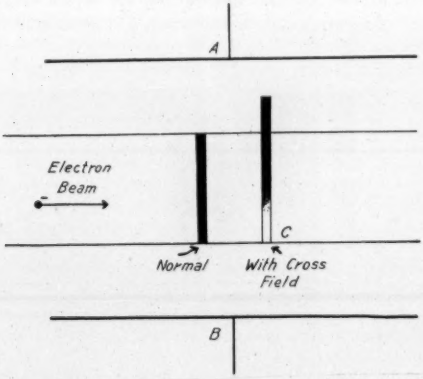
another electron is displaced from its normal orbit to some outer one. This atom is now capable of emitting two kinds of light, the arc line and the spark line. However, even concentrating our attention on the former, the emission of the line may not occur instantaneously because the electron may choose to remain for some time in the outer orbit. The field, however, will not permit the atom to stay still, it will have to move up on account of its charge, so that if the electron should remain in the outer orbit for a finite time, the bottom of the line in the spectrum—the place where the light first occurs, will be shifted upwards in relation to its normal position. Then, again, at a later stage, the atom may become neutral by the falling in of an electron from outside and this point will be shown by an increase of the intensity of the line at that place.

Then there is another possibility. Starting once more at the instant when the atom suffered its two-fold catastrophe, it may be that the electrons in some of the atoms start to fall to their normal positions immediately, while those in others take a longer time, so that there is some average time which an electron will remain in what we call its excited state without returning to its normal position of equilibrium. As most of the atoms remained in the excited state for a time very nearly equal to this average time, then on examining our spectrum we should find that while the spectrum would show something at the normal position at the bottom of the line, the intensity there would be very small and would not grow to an appreciable magnitude until some distance up. Without entering, therefore, into very great detail it will be clear that by studying the variation of the intensity of these spectrum lines along their length when they are excited in a field such as that which is produced between the plates A and B, we can learn much as to the nature of their production and as to the times which the atoms remain in excited states before they emit radiation. It will be of interest to note for example, that when an electron is thrown into what we may call an excited orbit it usually remains there for a time of the order of 10^{-8} sec. before returning to a position of stability. The year of a planet—the time taken for an electron to go around the

nucleus—is about 10^{-15} sec., so you see the prodigal son remains away from his home for something like 10,000,000 years.

I may illustrate the sort of information which Dr. Maxwell has been able to draw from his experiment by considering one particular case. The beam of electrons which is passing along the tube has a velocity comparable with that obtained by the fall of the electronic charge through 200 volts. These electrons have very much more energy than is necessary to

FIG. 11.

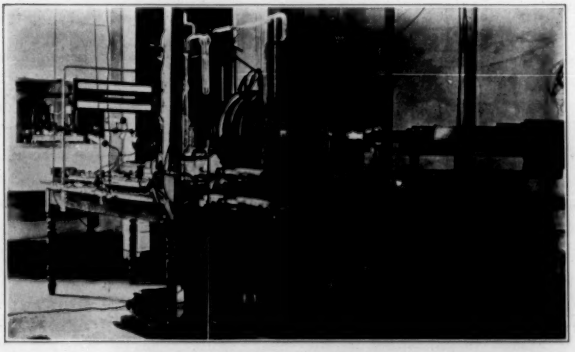


remove an electron from one orbit concerned in the optical behavior of an atom to an outer orbit, and we know from other considerations, that, under these conditions they would very rarely cause only such a removal. Electrons seem endowed with a peculiar type of philanthropic instinct—they like to give all that they have, or nothing at all!

Now, in the presence of the beam of electrons which passes through the tube in Dr. Maxwell's experiments we find that arc lines are generated. It was formerly thought that these arc lines were produced by the mere recombination of the ions into which the atoms of mercury vapor had been split by the arc beam, and this explanation was invoked because it was thought that the chance of a 200-volt electron

delivering to an atom such a small amount of energy as would correspond to the production of an arc line was so small that the intensity of the lines could not be accounted for by the assumption of such a process. By attributing the lines to a recombination of ions one was able to invoke an action in which, in the formation of the ions themselves, the electrons in the beam could part with a comparatively large amount of energy, an amount which they would be willing to part with comparatively readily. The thought was, when these ions recombined the energy of the recombination might be distributed among various lines in the arc spectrum produced. As against this supposition, however, Dr. Maxwell finds that

FIG. 12.



the arc lines are produced when the field between the plates A and B is so strong that the ions are removed so rapidly after their formation that there is practically no time for any ions to recombine in the beam. Moreover, the intensity of many of these lines is quite independent of the field between the plates A and B. We must thus seek for another explanation of the origin of these arc lines, and the one which has seemed most reasonable to Dr. Maxwell is the following: he supposes that the original 200-volt electron gives to an atom a comparatively large amount of energy, but

gives it to an electron well towards the center of the atom, by virtue of which that electron is carried to one of the outer orbits. If it should now fall back to its original orbit it would omit a line of too short a wave-length to correspond to the arc line—it would in fact emit an X-ray. However, Dr. Maxwell supposes that it does not do this, but falls from its outer orbit to another orbit less far out but still far removed from the orbit from which it came. Simultaneously with this however, it is supposed that the electron which formerly occupied this orbit falls to the central part of the atom, whence the original electron has come. In doing this, of course, it will emit an X-ray. One of the problems now before Dr. Maxwell is to search for these X-rays. Fig. 12 is a picture of Dr. Maxwell's apparatus. Time will not permit any detailed description of it. I should like to call your attention, however, to the circular structure towards the center, which constitutes a pair of Helmholtz' coils. Its function is to produce a very uniform magnetic field parallel to the axis of the tube which contains the beam of electrons. The electrons would, in the absence of this magnetic field, spread out by their self repulsion and the scattering of the gas. The magnetic field, however, serves to keep them in a beam according to well-known electro-magnetic principles.

A POSSIBLE EFFECT OF THE COSMIC RADIATION IN STIMULATING RADIOACTIVITY.

Another investigation which it is Dr. Maxwell's intention to carry out in the near future, is one pertaining to the cosmic radiation. It was suggested many years ago by Perrin that possibly the emission of radiations from radio-active materials was brought about by the cosmic radiation in the same sort of way that emission of electrons from atoms can be brought about every day in the laboratory by means of X-rays. Now Dr. Maxwell's thought is that by measuring the activity of a radio-active preparation in a deep mine, one could secure conditions under which the cosmic radiation would be cut down to such a large extent by absorption in the one-half mile of earth that if Perrin's conclusions are correct, the radio-activity of the substance should be very appreciably diminished—if not eliminated. Such a

test is now being planned by Dr. Maxwell for the early future.

THE PRODUCTION OF X-RAYS BY POSITIVE IONS

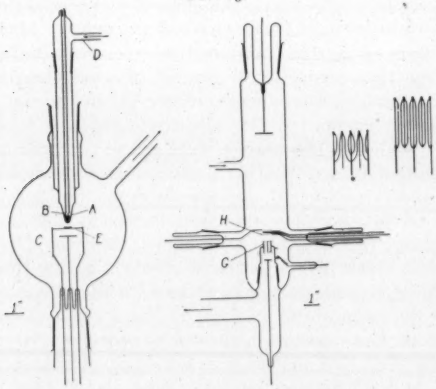
One of the most fruitful lines of attack in investigating matters pertaining to atomic structure lies in the utilization of X-rays. In fact, the study of X-rays in elucidating the mysteries of the atom is simply an extension of the study of the atom's spectral behavior which has given us so much in the past. The particular characteristics of X-rays resulting from their short wave-length serve to accentuate phenomena which are too weak to be observed in the case of light.

Strange as it may seem, and in spite of the detailed knowledge which we have of many of the properties of X-rays, one of the most elementary phenomena concerned with them, the actual production of the so-called general X-radiation is not, even at the present time, properly understood. We do know that if a beam of electrons is directed upon a metal target X-rays are produced, but under ordinary conditions only about one thousandth of the energy of a beam of electrons is converted into X-rays. The first picture which we had many years ago of the mechanism of production of these rays was one which regarded them as pulses produced in the æther when electrons were suddenly stopped by the atoms. If we have a ball with a number of elastic threads stretching out to infinity and if the whole system is in uniform motion in a straight line, sudden stoppage of the ball will create a pulse in the elastic threads, and this pulse will travel out to infinity. The classical electromagnetic theory explains the origin of X-rays in a manner very similar to that of these pulses, and it enables us to calculate the amount of energy which would go into the pulse under suitable conditions of stoppage of the electron. However, there are so many other phenomena in atomic physics closely related to X-rays and which the classical theory would not explain, that we are unable to admit an explanation along these lines. It is always a great help in the elucidation of the explanation of any phenomena if we can find more than one way of producing the phenomena, for under these conditions we are able to ferret out to greater advantage the essential elements which enter into their production. Now, we have two kinds of fundamental charged

particles in nature, the electron and proton—the proton being 1,800 times heavier and 1,800 smaller than the electron. There is every reason to believe that protons should be capable of producing X-rays, and indeed X-rays have been observed from them. The study of X-rays produced by two things as widely separated in nature as the electron and the proton cannot but give the most fundamental information as to the mechanism of the production. It will be of interest in the first place to compare the efficiency of production of the rays by these two kinds of charged particles. Then again, in the case of X-rays produced by electrons falling on a target, the rays comprise all manner of wave-lengths except that the shortest wave-length is one given by the relation $h\nu$ = kinetic energy of the electron, where h is Planck's constant and ν is the highest frequency. It will naturally be of interest to see whether a similar relation holds in the case of protons—to find out for example whether it is the velocity of the charge or its energy which is fundamental in determining this highest frequency. And so Dr. Henry Barton has taken up the problem of investigating the properties of X-rays produced by protons with the object of seeing how far the phenomena relating to X-rays and electrons are reflected in the case of X-rays and protons. It is rather surprising that this matter has not been attacked in detail before. It is probable that the reason lies in the difficulty of obtaining a beam of protons of sufficiently great intensity, for it appears on comparatively general considerations that the efficiency of production of X-rays by protons, is likely to be very much less than the efficiency of production by electrons, so that we should like to be able to produce beams of protons of intensity greater than those which we produce in the case of electrons. On the other hand, while we can with comparative ease produce beams of electrons carrying an ampere or more, it is not easy to get beams of protons to carry currents of more than a millionth ampere. So far Dr. Barton has been concentrating his attention upon methods for getting beams of protons which are as powerful as possible. We can readily obtain atomic hydrogen; and, if we bombard it with a beam of electrons we can ionize it. The positive ions of atomic hydrogen are, of course, protons. If we

bombard the atomic hydrogen in a tube we encounter the difficulty that if the density of the hydrogen is great enough to result in an appreciable production of protons, it will be so dense as to prevent the subsequent use of those protons for the production of X-rays. It occurred to Drs. Johnson, Bramley and Barton that one might defeat this difficulty by sucking hydrogen through hot platinum into a vacuum.

FIG. 13.



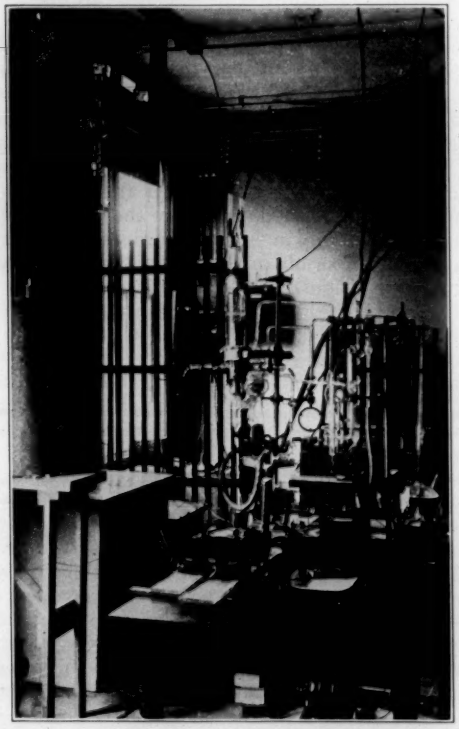
Gases are known to build up a relatively high density in any surface which they encounter, and it was thought that the hydrogen in coming through the platinum might build up a relatively high density on the surface as it emerged. If, as there is reason to believe, the hydrogen on the surface were in the atomic form, the bombardment of that surface by a beam of electrons would give rise to a copious source of protons, and these would be projected into a space of relatively high vacuum. The apparatus used for the trial of this idea is represented in Fig. 13. *A* is a thimble of platinum which could be heated by spiral *B* inside, it was surrounded by a vacuum in the vessel *C*, and the hydrogen entered through the tube *D*. It diffused through the thimble; and, as it emerged into the vacuum, was bombarded by a beam of electrons from the filament *E*. Unfortunately the method

failed to give any positive ion beam sufficiently powerful for the purpose in hand. By coating the outside of the thimble with various salts such as acid aluminum phosphate, more favorable results were obtained but it did not seem that the method would be likely to lead to beams sufficiently strong for the purpose. I shall not devote time to describing two or three other schemes which were tried but will concentrate on the vital one which seems to be likely to be successful.

Suppose we have a grid of holes such as is represented at *G*, contained in a tube in which hydrogen is present. The beam of electrons is accelerated upwards from a hot wire and passes through the hydrogen. Protons and electrons are formed by the impact of the electrons on the hydrogen molecules. It is now necessary to get these ions out of the tube where they are formed and where the pressure of the gas is relatively high, into a space where the gas pressure is sufficiently low to permit of the production of X-rays under satisfactory conditions. For this reason a grid *G* with reasonably long holes is utilized. A powerful pump operated on the lower side of the chamber draws out gas which diffuses through these holes, so that if the holes are not too wide and are sufficiently long it is possible to maintain a satisfactory vacuum in the lower part of the vessel even though pressure in the upper is as high as 0.05 mm. The idea is to draw the protons down to this grid by means of an electric field between the grid and the gauze *H*. If the holes are fine enough to permit of the proper evacuation of the lower part of the vessel it will be necessary for the protons to descend in a vertical beam in order to get through. Unfortunately the lines of force of the electric field bend to the edges of the holes and so tend to prevent the protons from passing straight through—they become diverted and hit the walls of the tube. If however, we cover these holes by gauze of very fine mesh, the distortion of the electric field in this vicinity is reduced very considerably as is indicated in the upper right corner of Fig. 13. If further we increase as much as possible the distance between this gauze and *H*, and increase in proportion the potential difference between these two gauzes, the situation becomes one in which the protons get a high velocity before they come into the region of the distorted field, and so pass

through the holes without colliding with the walls. In order to make a satisfactory investigation of the properties of X-rays produced by protons, it is necessary to have a beam of protons

FIG. 14.

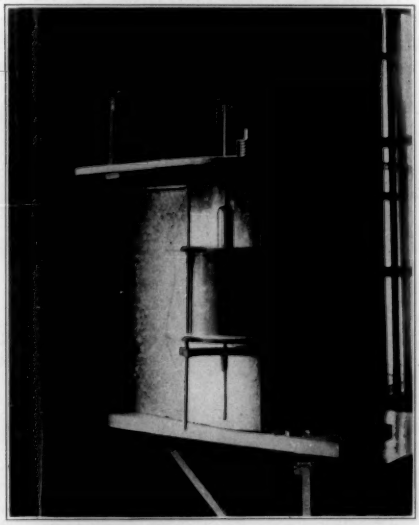


equivalent to about 10^{-4} amperes, and it would be desirable to have a beam of strength ten times this amount. Dr. Barton has succeeded in obtaining 10^{-4} amperes with the tube as

shown in Fig. 13 and with further modification has bettered that by a factor of 2, so that we now feel confident that with still further developments a beam of the order 10^{-3} amperes may be obtained. The complete apparatus is shown in Fig. 14.

In conclusion I may mention a little device which we have made up for measuring high potentials in connection with this investigation. Of course, there are many devices for this

FIG. 15.



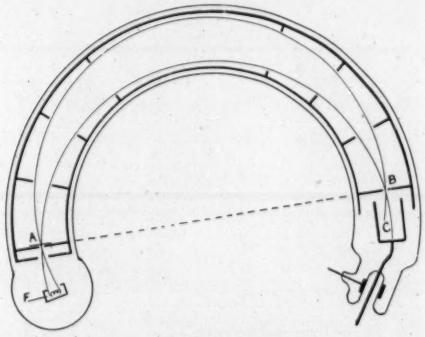
purpose, but the present one has an advantage of great cheapness and simplicity. It is represented in Fig. 15. It comprises a metal hydrometer floating in transformer oil and surrounded by a metal cylinder. The hydrometer has two light guides which keep it central and by whose means it is connected to earth. On placing the potential difference which it is designed to measure between the cylinder and earth, the field produced tends to suck the hydrometer

into the cylinder to an extent which is recorded by the motion of the top of the stem. By placing a scale on the top and directing a beam of light through it in such a way as to throw its image on the screen, a convenient means of recording the readings is provided.

THE LOSS OF ENERGY BY ELECTRONS IN THE PRODUCTION OF CHARACTERISTIC X-RADIATION.

Another investigation on X-rays is one which is being carried out by our Lady Fellow, Dr. Allen. It has to do with what is known as the characteristic X-radiation. When electrons strike a metal, in addition to the general radiation of all wave-lengths which comes off, there are certain special wave-lengths characteristic of the atoms of the metal which

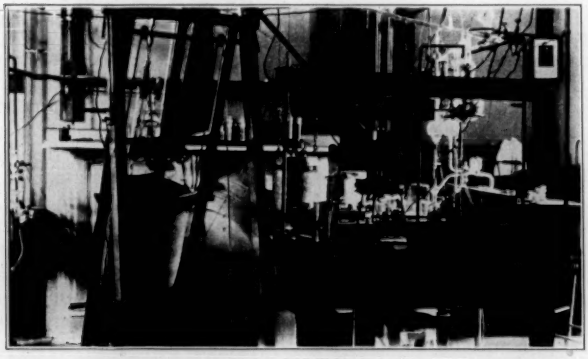
FIG. 16.



come off in amounts enormously great compared with the amounts given off in the corresponding wave-lengths of the general radiation. If we pass electrons through a thin foil of metal we may expect to find them divided into two groups: those which lose hardly any energy at all, and those which have been concerned in the production of the characteristic X-rays and whose velocity will have been reduced by a very considerable percentage of its original amount. We can sift out the electrons of different velocities by a principle which is well-known in experimental physics. The electrons emerging

from the filament F pass through two slits and through the foil. The beam so formed is then bent into a circle by a magnetic field perpendicular to the plane of the paper (Fig. 16); and, according to well-known electromagnetic principles, becomes focused at the other end of the diameter AB. If the velocity of the beam were altered, the radius of the cylinder into which it was bent would be altered or it could be made the same size by varying the magnetic field responsible for the deflection. In other words, by placing at B, Fig. 16, a little cylinder, C, it was possible to collect the beam and record it on a suitable galvanometer or electrometer. Further, by

FIG. 17.



adjusting the magnetic field, it was possible to bring electrons of any velocity into the little cylinder. It will readily be seen that the method affords a means of determining the relative magnitudes of the currents carried by electrons of different velocities. While it would take a long time to go into the theoretical details of all that may be concluded from experiments having to do with the loss of velocity of electrons in passing through thin foil it may be said that by measuring the relative numbers corresponding to this loss of velocity we can draw much valuable information as to the nature of the processes which have taken place in the interaction

between the atoms and the electrons as the latter pass through the metal.

AN ATTEMPT TO DETECT A MAGNETIC FIELD AS A RESULT OF THE RAPID ROTATION OF A COPPER SPHERE.

For many years the question has been mooted as to whether a body could give rise to a magnetic field as a result of mere rotation. I am not now referring to that magnetizing action which arises, particularly in the case of magnetic substances like iron and nickel when set in rotation, from the gyroscopic action on the electronic whirls whose existence in the atoms give those atoms their magnetic character. This phenomenon is now well known and has been very thoroughly investigated by Prof. S. J. Barnett. I am referring rather to the possibility of a magnetic state arising from even more subtle causes bound up with the ultimate nature of the laws of electrodynamics. The question arises in connection with endeavors to account for the earth's magnetic field. The earth is a great magnet. It cannot be a magnet in the sense that a piece of magnetized steel is a magnet because its interior is too hot. The earth carries an electric charge, and this by its rotation would give a magnetic field, but a field only 10^{-8} of the earth's magnetic field. Again, the free electrons of the earth's substance will tend to be whirled to the exterior, so that the rotation of the resulting distribution of charge will give rise to a magnetic field, but calculations show this field to be only 10^{-23} of the earth's magnetic field. The pull of gravity on the electrons will make them tend to move slightly towards the earth's center, but here again, calculation of the effect gives a magnetic field only 10^{-21} of the earth's field. The fact that the center of the earth is hotter than the exterior could result in the free electrons in the central part exerting a greater pressure than those in the outer regions, and this excess pressure would result in slight motion of the electrons. The rotation of the charge distribution thus formed would give rise to a magnetic field, but a field only 10^{-17} of the earth's field.

There is so much positive and negative electricity in a cubic centimeter of matter in the substance of the earth, for example, that if all the positive electrons in one c.c. of the earth could be collected at one point and all the negative

electrons in that c.c. could be collected at another point, 1 cm. away, the two would attract each other with a force equivalent to 10^{20} tons. If we could annihilate the positive electricity in the earth, the negative would give by its rotation a magnetic field 2×10^{18} times that of the earth. If all the positive electricity in the earth could be collected into one sphere and all the negative electrons into another concentric with the first but a little larger, the combined rotation of the two would give a magnetic field, and it would only be necessary for the two spheres, each of the size of the earth, to differ in diameter by 10^{-10} cm. in order that the field resulting from their rotation should be as great as the earth's field. This matter was pointed out by Sutherland many years ago; but, tempting as it seems as the basis of a possible explanation of the earth's magnetism, the existence of such a state of affairs involving even such a slight separation of the charge could not come about in practice owing to the tremendous electrostatic forces which would come into play to protest against even this small separation. And so many attempts to account for the earth's magnetism along what may be called normal lines have led to a disappointment. The fact, however, that each of the two kinds of electricity which make up the earth would by its rotation alone give rise to such an enormous magnetic field, suggests that possibly some very slight difference between the laws of electromagnetism for positive and negative electricity might result in a departure of the two kinds of electricity from a complete balance, and so leave the earth's magnetic field as a residual.

A short time ago I showed how it would be possible to make a modification in the laws for positive and negative electricity such as would result in the rotating earth giving rise to a magnetic field, and such as would further account for the origin and maintenance of the earth's charge and the force of gravitation, the whole being moulded into one complete scheme consistent with the theory of relativity.

The theory makes the sphere act as though it were endowed with a current density, and, depending upon the way in which this apparent current density varies with distance from the axis of rotation, it gives various possibilities as regards the way in which it makes the magnetic field depend

upon the radius and angular velocity of the rotating sphere. This is fortunate for it is necessary that matters should be adjusted so as to correspond to certain requirements imposed by the facts. We know that the sun has a magnetic field, and any theory which is to correspond to the facts must, when adjusted to fit the earth, give the right value for the sun when the radius and angular velocity of that body are substituted in the formula. Moreover, if we apply the theory to the case of a small body rotating with very high speed in the laboratory, it should not suggest for that body a large magnetic field for if such a field existed in appreciable amount, it would certainly have been found before now.

FIG. 18.

	Relative Values				
	S	E	100 rev/sec $a=10$ cm	$i\alpha$	$H\alpha$
a	7×10^{4}	6.4×10^{7}	1		
ω	1	25.5	2.2×10^{8}		
H_z	58	0.5	1.0×10^{-9}	$Dr\omega$	Dwa^2
H_z	0.1	0.5	7.8×10^{4}	$Dr\omega^2$	Dw^2a^2
H_z	42	0.5	1.7×10^{-4}	$Dr^3\omega^4$	Dw^4a^4

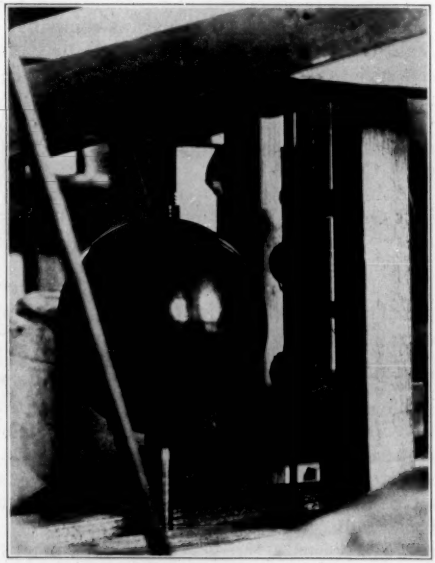
Fig. 18 shows the results which follow from adjusting the theory to correspond to a current density proportional to $r\omega$, to $r\omega^2$ and to $r^3\omega^4$, ω being the angular velocity and r the distance from the axis of rotation.

In the case where the apparent current density is proportional to $r\omega$, if matters are adjusted so as to give the right value for the earth (0.5 gauss) at the pole, the value which it would predict for the sun at its pole is 58 gauss which is good agreement with the actual facts. On the other hand, it suggests for a small sphere of 10 cms. radius, and of the earth's density rotating 100 times a second a magnetic field of only 10^{-9} gauss which would be quite immeasurable.

A current density proportional to $r\omega^2$ would lead to far too small a magnetic field for the sun, and far too large a field for the small body.

A current density proportional to $r^3\omega^4$ would lead to a satisfactory value for the sun, and for the small body would

FIG. 19.



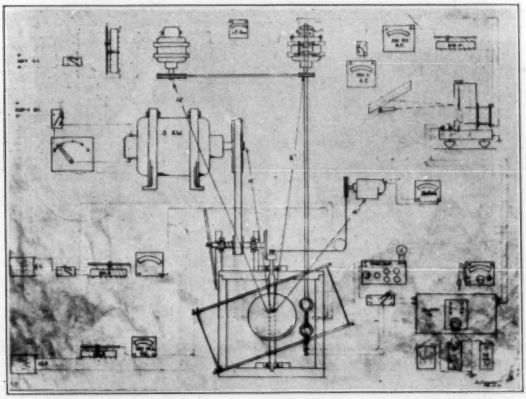
lead to a field just within the range of measurability. It turns out that these two forms of law, one in which the effective current density is proportional to $r\omega$ and the other where it is proportional to $r^3\omega^4$ are the only forms comprising simple powers of r and ω which could be consistent with the facts as regards the sun and the small body rotating at high speed in the laboratory. Mr. Longacre and I have been carrying out an experiment in an endeavor to determine any

magnetic field which may be produced by a comparatively small body rotating at high speed. The body which has been used is shown in Fig. 19. It is a solid copper sphere 8 in. in dia., and we have rotated it up to speeds of about 200 revolutions per second. On the basis of an effective current density proportional to $r\omega$ the field even at this speed should be quite negligible, but on the basis of the law which makes the current density proportional to $r^3\omega^4$ we should, taking into account the greater density of copper as compared with the earth, obtain here a field of the order 4.3×10^{-3} at the pole. At half this speed the field would only be 1/16 of this amount so that any field of this origin would show itself by a very rapid increase with the speed once it became evident at all. It is of course, not a very easy matter to measure a field of the order of 10^{-3} gauss under conditions in which one is rotating a 8 in. copper sphere 200 times a second. There is apt to be a good deal of shaking, and the ordinary astatic magnetometer is not a convenient device. For this reason we have used the principle of two coils wound in opposite directions, rotating near the sphere, and about a vertical axis. These coils feed into an amplifier from which the current goes to an alternating current galvanometer. As far as any uniform field is concerned, the two coils being wound in opposite directions, annul each other's effect, but as far as the magnetic field of the sphere is concerned they are additive in their contributions. I must not enter into details of the commutation devices, which, however, have to be attended to with the greatest care in order that spurious electromotive forces shall not mask the quantity which it is desired to measure.

Figure 20 represents the general set-up, practically the whole of the apparatus having been made by Mr. O. Steiner, our chief instrument maker. The sphere was driven by a friction drive using a 3 kilowatt motor, the rotating coil compass being driven at about 150 r.p.s. by a belt drive from a distant small motor. The field coils for the alternating current galvanometer were supplied from a small generator, mounted on the same shaft as the compass. The speed of rotation was measured by means of an electric tachometer. Some preliminary experiments were carried out

in the laboratory at N. 19th Street, and then in order to secure the best possible conditions for the final experiments, we transported the apparatus to Swarthmore, where, through the courtesy of Dr. Simpson and Dr. Wright we were able to set up the equipment and carry out measurements under more advantageous conditions. Fig. 20 represents the set-up

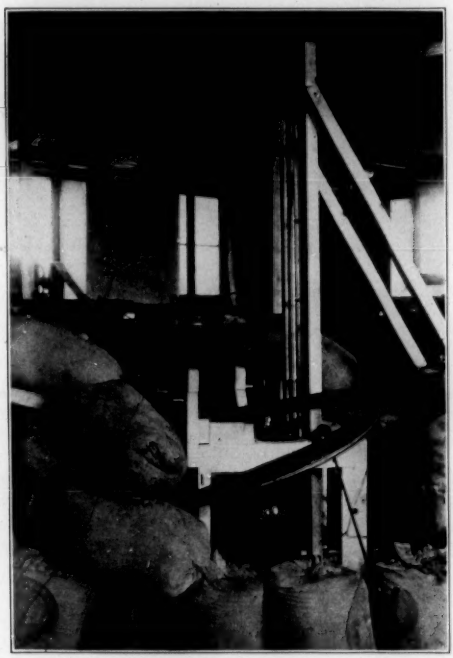
FIG. 20.



of the apparatus at Swarthmore. We are running so near the point at which the sphere would fly to pieces on account of the tremendous centrifugal force—a force which amounts to about 140 kilograms on each cubic centimeter near the surface of the sphere that it is necessary to surround the apparatus with sandbags in case of an accident. Fig. 21 represents the actual apparatus, and Fig. 22, the sort of results which were obtained. At first sight it appears that one obtains a comparatively large magnetic field if the speed is increased (curve *B*). This, however, is a spurious effect and arises from the Foucault currents which are set up as a result of the sphere's rotation in the earth's magnetic field. These currents act in such a direction as to tend to shield the sphere from this magnetic influence and it is of interest to observe how

the effect approaches a sort of saturation value. In order to eliminate this effect we surrounded the sphere by a pair of Helmholtz coils shown in Fig. 20. The current in these coils was adjusted so that the earth's field was compensated and

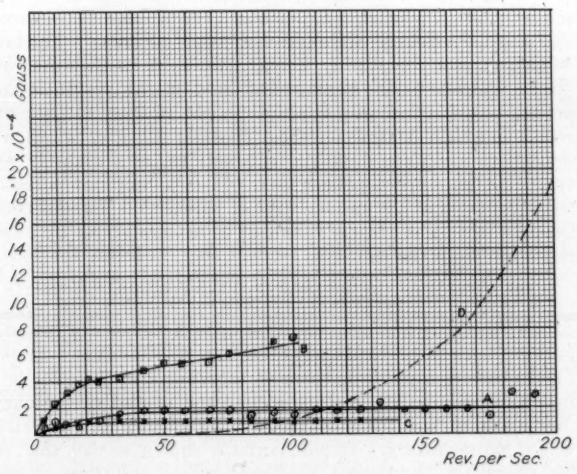
FIG. 21.



under these conditions curves A and C of Fig. 23 were obtained for the variation of the magnetic field with speed. Curve D represents the results which would have been obtained on the basis of the current density proportional to $r^3\omega^4$ and with a constant factor adjusted to fit the earth's field. The

magnetic field obtained is thus definitely smaller than would be predicted by such a law, and is more in conformity with the other type of law which makes the field proportional to $r\omega$. It is, however, worthy of note that in expecting a correspondence between the form of the law for the conditions pertaining to the earth and those pertaining to the small sphere we are extrapolating over an enormous range. I can illustrate the situation in this respect by supposing that the

FIG. 22.



current density, instead of being proportional to $r^3\omega^4$ were proportional to $r^3\omega^{3.8}$. This very slight difference in the power to which ω is raised would result in an alteration of the field predicted for the small sphere from 43×10^{-4} to 1.5×10^{-4} and the latter would be immeasurable with the present apparatus. This experiment, therefore, does not drive us to the necessity of giving up the law determined by a current density of the form $r^3\omega^4$ for bodies of cosmic size and angular velocity, and there are certain very interesting conclusions which would follow from the form of such a law. We know

that in sun spots magnetic fields of the order of 2,000 gauss are encountered. The modification of electrodynamics to which I have referred would suggest that these might arise from the mere rotation of the matter of the sun spot, and when we submit the question to examination it turns out that on the basis of the law which makes the current density proportional to $r^3\omega^4$, it is only necessary to assume a velocity of gas in the spot of the order 80 kilometers in order to provide for a magnetic field of 2,000 gauss. Moreover, this form of law leads to interesting conclusions when applied to the planet Jupiter, which has a diameter 11 times that of the earth and angular velocity two and a half times as great. The law would suggest for Jupiter a magnetic field of the order of 50,000 gauss. Such a magnetic field might result in an aurora of great intensity for this planet, in view of the grip which it would have upon those charged particles which we believe to emanate from the sun and to be ultimately responsible for aurora phenomena. It is a fact not without significance, that the surface light of Jupiter has for sometime been known to be greater than can be accounted for by mere reflection from the sun.

THE EFFECT OF AN ELECTRIC FIELD ON THE PRODUCTION OF DOUBLE REFRACTION IN SODIUM VAPOR.

Dr. Bramley has been engaged upon a number of investigations, both theoretical and experimental. Much as I should like to devote some time to these theoretical investigations I fear it would be impracticable in view of the preliminary discussion of the basis of modern atomic structure which would be necessary. It will perhaps suffice to say that in his paper on Dynamical Problems, whose solutions satisfy Schrödinger's Wave Equation published in the Journal of the Franklin Institute last November, the aim was to mould the fundamental characteristics of modern atomic theory into a form more in harmony with the classical ideas in which our thoughts have grown up.

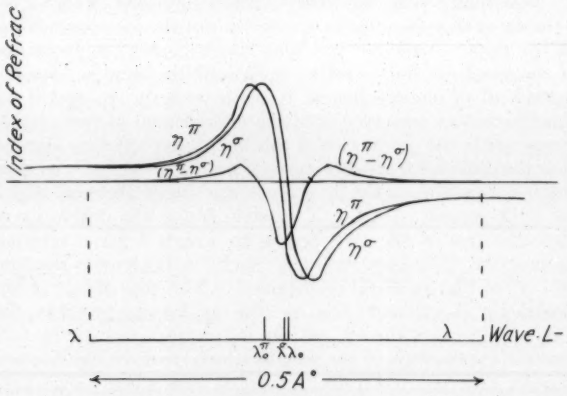
On the experimental side, Dr. Bramley has been interested in analyzing the nature of a certain type of atomic process by performing experiments on sodium vapor. If plane polarized light from a sodium flame be passed through a tube containing sodium vapor, and if a transverse electric field be applied

across the tube, then for the general case where the line of vibration of the incident light is inclined to the direction of the field, the light becomes split up into two beams, in one of which the vibrations are parallel to the field and in the other perpendicular to the field. These two beams travel through the vapor with different velocities, and the effect is to produce what is known as elliptically polarized light.

Now many years ago, the German physicist, Voigt gave a theory of this phenomena on the basis of the ideas prevailing at the time. Although the light which comes out from one of the spectrum lines emitted by a sodium flame is approximately all of one frequency, it is not exactly so, and if we should concern ourselves with the short range of frequencies comprised in the production of this line, Voigt's theory showed that the different frequencies comprised in the range would be treated very differently by the sodium vapor through which the light passed. In fact, if we should plot the difference of the velocities of the two beams to which I have referred against the frequency, a curve such as the curve marked $(\eta^{\tau}-\eta^{\sigma})$ of Fig. 23 would be obtained. Now, the object of Dr. Bramley's experiment was to test as far as possible the conclusion of this theory, and its importance lies in the fact that the explanation of the way in which these things happen is quite different today from what it was when Voigt propounded his theory. The ideal way of making the test would of course be to use light of such a well-defined frequency as could enable a test of Fig. 23 to be made directly, but it is impracticable to pick out from the whole line emitted by the flame several portions and deal with them separately. Nevertheless, the theory does lead to information as to what would be the effect of the vapor and electric field on the average difference of velocities of the two beams for the whole range of frequency comprised in the line. In order to interpret the results obtained we must know the distribution in intensity as a function of the frequency over the frequency of the line. This has been determined by former investigations; it is known that the intensity varies over the line according to some such law as that represented in Fig. 24, a minimum of the intensity existing at that frequency which corresponds to the exact center of the line. Making use of

this curve, we can calculate what the effective average difference in velocity would be when the light from the whole line is passed through the vapor. It was found that so long as the temperature of the vapor was greater than 230° C. the results were in agreement with Voigt's theory, but below this temperature they departed from that theory.

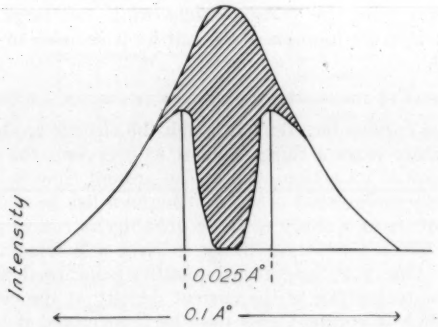
FIG. 23.



Now in Voigt's theory the basic idea of interest in the explanation of the process lay in the supposition that the atom of sodium vapor acted like a little electric oscillator which could be set into vibration by the light, and the function of the field was to orientate this oscillator. On modern views, the atom acts towards the light in the capacity of two oscillators, one parallel to and one perpendicular to the field; but these oscillators do not exist continually; they come into existence only now and again, and the chance of their coming into existence depends upon the temperature and the electric field. The electric field acts in a manner different for the two, while the temperature is more impartial. Thus we should expect that at high temperatures, the chances of these two virtual oscillators as we may call them, coming into existence, would be more nearly equal than would be

the case at lower temperatures where the electric field has a greater control of the situation. Now it turns out that although the mechanism of the process is quite different for the classical and newer theories, the results predicted by the two theories would be the same if the chance of the two kinds of oscillators coming into existence were the same. We thus see why it should come about that Dr. Bramley's experiment

FIG. 24.



should agree with the classical theory at high temperatures and disagree with it at low temperatures. The most interesting part concerns, of course, the disagreement at low temperatures since here we obtain from that disagreement information as to the differences in the action of the electric field on the two kinds of virtual oscillators.

THE VARIATION OF DIELECTRIC CONSTANT OF A SOLUTION WITH CONCENTRATION OF THE DISSOLVED SALT.

Another experimental investigation carried out by Dr. Bramley concerns the effect of a dissolved salt on the dielectric constant of the solution. I have already referred to the importance attaching to a knowledge of the mechanism of processes occurring in solutions, particularly in relation to their electrical conductivity. The theory of the origin of the dielectric constants of solutions is bound up with another aspect of the same question; and indeed a theory has been

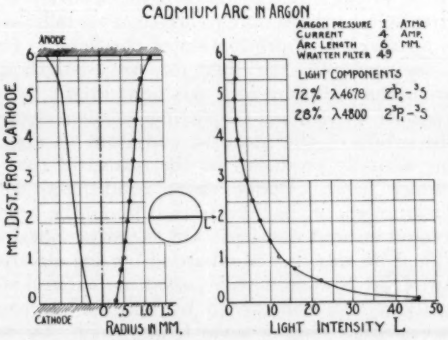
worked out by Debye and Hückel to account for the variation of dielectric constant with concentration. Time will not permit me to do more than say that former experiments which have been performed on this matter lead to contradictory results among themselves. By adopting a new and particularly sensitive method for measuring the dielectric constant, and one free from the objection inherent in former determinations, Dr. Bramley has measured the dielectric constant for solutions of various strengths, and has shown departures from the theory which, while not large enough to affect it in its fundamentals, call for a revision in matters of detail.

THE NATURE OF THE PROCESSES OCCURRING IN CERTAIN ELECTRIC ARCS.

It is a curious fact that although the electric arc has been for so many years a thing familiar to everyone, the detailed mechanism of its action even at the present time is far from completely understood. Mr. Nottingham has been devoting his attention to a study of those phenomena concerned with the arc which seem most likely to have a bearing upon its theory. One very important quantity concerned with the arc is the magnitude of the current density at the electrodes from which it springs; this may be determined if the area of what is known as the hot spot can be measured with sufficient accuracy. It would seem at first sight that all that would be necessary to accomplish this purpose would be to photograph the arc and then measure the photograph. Unfortunately, however, the relation between the intensity of the light coming from a source and the density of the photographic image produced on the plate is such that an assumption of their proportionality would lead to an error of as much as 50 per cent., even in the measurement of as apparently simple a thing as the size of the hot spot. Moreover, in the acquirement of information as to the variation of light intensity over the arc, information bound up with the details of the mechanism of the action in various parts, such an assumption would lead to very drastic errors of conclusion. For this reason it has been necessary for Mr. Nottingham to go very carefully into the nature of the photographic process in the interpretation of his photographs. Fig. 25

shows, to the left, the curve which is typical of the kind of results obtained for the change in radius along the arc. The radius is measured horizontally and the distance along the arc vertically. The boundary of the arc as determined by this method is quite definite and leads to measurements of the areas of the hot spot on the cathode to an accuracy of about 5 per cent. It turns out that the area of the cathode is proportional to the total current so that the

FIG. 25.

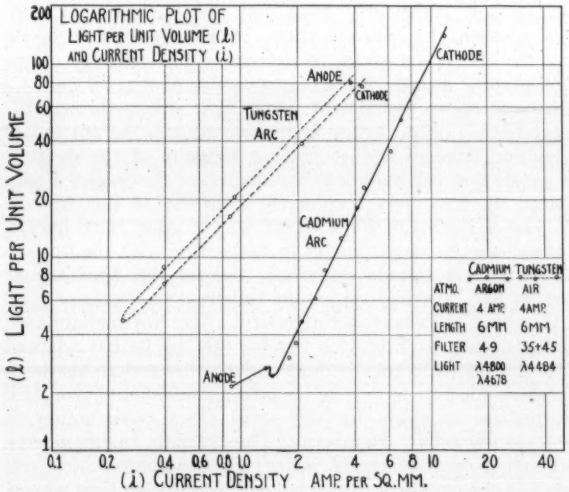


current density is constant, and it turns out that in case of the tungsten arc this current density is 700 amp. per sq. cm. It so happens that this represents the current which could be produced by thermionic emission of the electrons at a temperature of 3700° K which is just the melting point of the tungsten, so that in this case it is not necessary to invoke anything but thermionic emission to account for the electrons emitted from the cathode. A similar result holds in the case of carbon, but here the current density is about 300 amp. per sq. cm. In copper and cadmium, however, we are confronted with quite a different situation. Here the current density turns out to be of the order of 3,000 amp. per sq. cm. for copper and 1,500 amp. per sq. cm. for cadmium. These are much greater than it is possible to account for upon the basis of mere thermionic emission at the temperature of the cathode. One's first thought might be that a considerable

portion of the current would be carried by positive ions, but in view of the very much greater mobility of electrons as compared with positive ions such an assumption would necessitate an existence of an excess density of positive ions over negative in the arc quite prohibitive in view of the enormous electrostatic repulsion which would arise from this positive density. For the moment we must regard the origin of these high electron current densities in the case of copper and cadmium as something of a mystery. By a consideration of the distribution of light intensity in the arc, Mr. Nottingham has been able to arrive at certain conclusions as to the mechanism of production of the light. Thus, considering, for example, the light of wave-length 4,678 Å. coming from the cadmium arc, this light might be produced as the result of an electron displacing another electron from one of the orbits of the atom of cadmium to another, the light being actually produced on the return of that electron to its former orbit. Under these conditions, we should expect the intensity of the light in that line to be proportional to the electron current density. On the other hand, it might be that the atom was first bombarded by one electron which put it into what is customarily called, an excited state, and subsequently it was bombarded by another electron which took it to another energy level from which, by return to the first or second level, it emitted the light observed. In this case the light would be proportional to the square of the electron current density. Thus by examining the relation between the light intensity in a line and the current density, we may draw information as to the nature of the production of the light. In case the intensity is proportional to the square of the current density, then on plotting the logarithm of the intensity against the logarithm of the current density it is easy to see that the slope of the straight line obtained should be just equal to 2, and this is exactly what is found for the lines 4,800 Å. and 4,678 Å. in the case of the cadmium arc which is represented by the straight line shown in Fig. 26. The curve for the tungsten arc corresponds to the line 4,484 Å. The observations from both the anode and the cathode regions lead to straight lines, each having the slope unity. This indicates that the light was produced by single impacts

of electrons. With regard to the way in which these data were obtained it will suffice to refer once more to Fig. 25. This particular curve was obtained, for example, with a filter which let through 72 per cent. of 4,678 Å. and 28 per cent. of 4,800 Å. The total light received at different points along the arc is represented by the curve to the right, and this, when

FIG. 26.



divided by the diameter of the arc at the corresponding point, serves to give the light intensity per unit volume. The details of this conclusion involve a rather careful consideration of the geometry of the optical arrangement, etc., and are not immediately obvious, but I will not enter into this matter at present. Many other things might be said in this connection but perhaps the results which I have quoted will serve to give an indication of the type of information which Mr. Nottingham has been able to draw from data of this kind. Then again, if we are to suppose that the electrons produce transitions in the atoms of such a nature

as to account for the lines in the manner I have indicated, it is necessary to invoke in those electrons a certain minimum velocity, and one which is greater than could be given to those electrons by the field while traversing one of their mean free paths. For this reason, Mr. Nottingham has made a direct determination of the velocities of the electrons in the arc, using a method designed by Dr. Langmuir for such processes. It turns out that the average electron energies are sufficiently high for the purpose. In connection with this investigation, it was of course necessary for Mr. Nottingham to determine the densities of the photographic images of his plates by use of what is called a densitometer, an instrument where light shines through the image onto a photoelectric cell which records the amount of it coming through and so gives a measure of the density. As we do not yet have a densitometer at the Bartol Foundation, we have relied upon the courtesy of our friends. Dr. James Barnes of Bryn Mawr was so good as to let Dr. Maxwell use his densitometer in connection with the investigations I have already described, and for the densitometer used by Mr. Nottingham we are indebted to Professor Karl T. Compton of Princeton University. Mr. Nottingham used the instrument at Princeton but for this use he has adapted it to the photoelectric method and to this end it has been necessary for him to crystallize into a convenient form such information as exists for the satisfactory construction of photoelectric cells. Members of The Franklin Institute have had ample opportunity of seeing what a photoelectric cell can do in the matter of transmission of sound over light waves, etc. I should like to exhibit here another aspect of the potentialities of these cells and one which exhibits its great sensitivity. We have here one of Mr. Nottingham's cells which is connected through a suitable relay to an electric bell. By striking the match at the other end of the room, I hope, if all goes well, the bell will ring. While Mr. Longacre will strike the match at the other end of the room, and while Mr. Nottingham and Dr. Barton are here in the vicinity of the apparatus I can assure you it is their intention to exert no more than a moral influence upon it. Now, Mr. Nottingham has calculated that with the arrangement which he has

adapted in the cell as used with the densitometer the conditions would be equivalent to observing the light from this match at a distance of one third of a mile, and with the use of still more sensitive arrangements it would be quite possible that the match could be detected at the distance of three miles.

THE REFLECTION OF HYDROGEN ATOMS FROM CRYSTALS.

I wish to turn, now, to another type of experiment.

Our endeavors to understand the atom have led us into a maze of complexities. At the end of the last century we were coming to a stage of contentment in the belief that light was satisfactorily explained as a wave motion of electromagnetic nature propagated in the all-pervading medium—the ether. We learned to think of electricity as composed of small particles, electrons and protons which our minds pictured as little spheres; the electron having a radius of the order 10^{-13} of a cm. and the proton a radius 1,800 times smaller. No sooner had we adjusted our mental equilibrium to this view, however, than nature revealed some facts which seemed to show that light was propagated in a manner more characteristic of a flying particle than of a spreading wave, and that X-rays and the gamma rays of radium were also of this particle nature. The light ray was a sort of Dr. Jekyll and Mr. Hyde. The electron did stand out, however, in our minds as a thing of less capricious nature and no one suspected it of leading a double life. However, in the last two or three years our whole views of the mechanism of atomic structure have undergone a very radical change and the scrutiny which the new views have imposed on the electron have shown that he also is not above suspicion. The detectives were set to work upon him with the result that in the famous experiments of Davisson and Germer he was caught in the act of doing something which nobody ever believed that he could do—the act of posing as a wave instead of as a particle. This immediately threw suspicion on all things like him—the atom included, and the theory of the whole business confirmed the viewpoint that the atom was probably guilty too. Of course, the detailed investigation of phenomena of this kind constitutes one of the most important lines of attack in our endeavor to understand the

ultimate nature of things, and Dr. Johnson has been seeking to ascertain whether an atom of hydrogen may or may not be made to act in the capacity of a wave. In order to illustrate the nature of the temptation to which Dr. Johnson has subjected the atomic hydrogen I must recall to your minds the fact that many years ago, physicists succeeded in ruling very finely spaced lines on speculum metal in such a way as to constitute a grating. When light is caused to fall on such a grating it is not reflected off in a simple manner as in the case of an ordinary mirror, but the reflection occurs in certain definite directions depending on the wave-length of the light. The shorter the wave-length of the light the more closely is it necessary to rule these lines in order to exhibit this effect. It would be quite impossible to rule a grating which would serve in all respects for X-rays as our former gratings serve for light, because the spacing of the lines would have to be too fine. Within the last fifteen years, however, an enormous development both in our knowledge of the structure of matter, and X-rays has come about by realizing that in the regularities of structure which we find in crystals nature has succeeded in providing us with just the sort of gratings which are appropriate for use with X-rays. The theory of these gratings is a lot more complicated than the earlier diffraction gratings. They are in fact three-dimensional gratings; and, if a beam of X-rays of definite quality be allowed to fall upon the surface of such a crystal, there will in general be only a certain angle of incidence at which reflection will occur, and the angle of reflection will in each case be equal to the angle of incidence. If we had to deal with X-rays which, like light, could penetrate only a very short distance into the crystal, that crystal would act like a surface grating. There would be reflection for every angle of incidence, but for each angle of incidence there would be a set of different reflected beams. Now, in the experiments of Davisson and Germer to which I have referred, it was found that on sending a beam of electrons onto such a crystal the beam behaved in a manner similar to X-rays, in giving rise to definite reflected beams. Before this time everyone believed that electrons were particles.

In carrying out experiments designed to test the possibility

of such behavior in the case of atoms it is first necessary to decide upon a grating of suitable spacing. As regards the atoms to be used in the experiment it was decided to try atomic hydrogen, since this represents one of the simplest types of atoms, and an atom, moreover, which would correspond in theory to types of X-rays which are most convenient to work with. In experiments of this kind it is very necessary that the surface from which reflection occurs shall be maintained absolutely clean. For this and certain other reasons Dr. Johnson decided to use in the first instance crystals of ice.

FIG. 27.

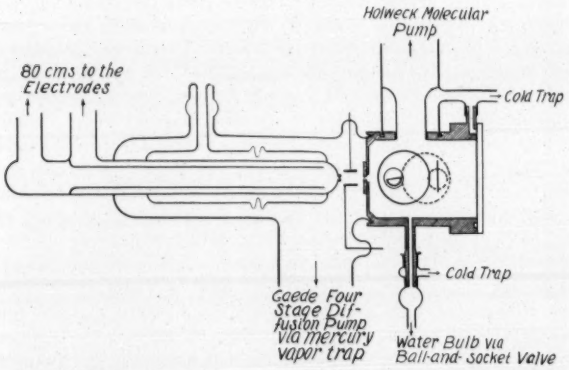

Holweck Molecular Pump
80 cms to the Electrodes
Cold Trap
Cold Trap
Gaede Four Stage Diffusion Pump via mercury vapor trap
Water Bulb via Ball-and-Socket Valve

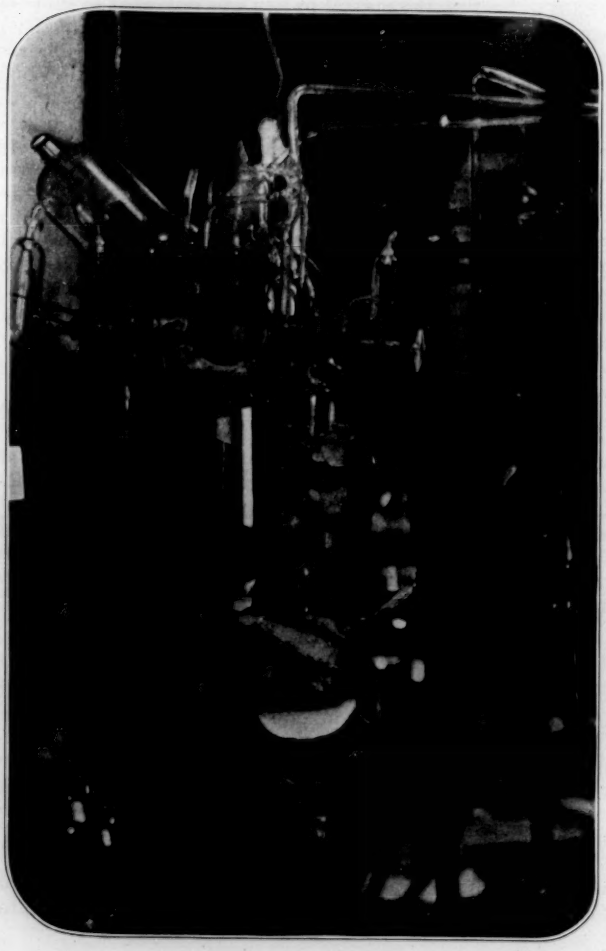
Fig. 27 represents the general scheme of the apparatus. By sending an electric discharge between the electrodes through the space which can be readily traced out in the figure and which was filled with hydrogen, a copious supply of atoms of hydrogen was produced. The portion of the discharge tube shown in the figure is surrounded by a double-walled vessel which could be filled with water to control the temperature. Through the slit indicated in the discharge tube the atomic hydrogen shot, with a velocity of about 300,000 cms. per second towards the slit in the metal chamber, which is shown dark. The atoms which failed to pass through the second slit were prevented from clogging up the space by means

of a powerful four stage diffussion pump which cleared them out very rapidly.

The beam of hydrogen which passed through the slits fell upon a little surface, which was a plane-plate of glass covered by crystals of ice frozen onto it from vapor which was allowed to enter the metal chamber at frequent intervals. The glass plate was kept cool by maintaining it in contact with liquid air by an arrangement which is not shown in the figure. A Holweck pump served to prevent the accumulation of atoms in the metal chamber as a result of the entrance of the beam. The ice of course existed in the form of a great many minute crystals oriented in all sorts of different directions. A glass plate covered with molybdenum oxide was arranged to catch any reflected beam. The atomic hydrogen left its record by turning the oxide blue. If the ice crystals acted as three-dimensional gratings, only such crystals as were properly oriented in relation to the original beam would reflect the atoms, but we could always expect that there would be enough crystals so oriented for the purpose. The reflected beams if they occurred would be found inclined to the original beam at definite angles determined by the grating space of the crystal and the wave-length to which the atoms of hydrogen, treated as waves might be supposed to be equivalent. If, however, the atoms of hydrogen failed to penetrate through the surface layer of the crystal we should expect that such an arrangement as this would fail to show any definite reflected beams, and it would be necessary to use a single crystal of definitely defined surface to obtain such reflection. In the first experiments which Dr. Johnson carried out he did obtain records which seemed to indicate reflections of the atomic hydrogen beams of the kind sought. However, further investigation revealed the probability that these records were caused by phenomena other than crystal reflections.

When it seemed likely that the atomic hydrogen did not penetrate sufficiently far into the ice to permit of the realization of the three-dimensional grating reflection, Dr. Johnson turned his attention to the use of a single crystal, but since it was impracticable to grow a single crystal of ice in the apparatus he decided upon rock salt. The same apparatus

FIG. 28.



was used for experiments with this crystal except that a means of heating the crystal in situ was provided so that the accumulation of gas on its surface could be prevented. By a curious coincidence, it was only yesterday, that Dr. Johnson obtained, from a crystal grating, the first real reflection of a beam of atomic hydrogen characterized by equality of angles of incidence and reflection. Thus, here again we find a phenomenon consistent with the view that particles, now atoms of Hydrogen, can behave as waves behave. It is true that if we confine ourselves to specular reflection the phenomenon could also be accounted for by the assumption of a repulsive force perpendicular to the surface of the crystal. There are certain respects, however, in which the wave hypothesis has a greater richness of content in respect of what it predicts than has the repulsion hypothesis, and further investigations are now in progress with the object of distinguishing between the two views. Fig. 28 shows the complete apparatus which was used in these experiments. I wish I could take the time to describe it in detail as it offers many devices which have been originated and which will be of service in many other investigations, as, for example, an entirely new form of liquid air trap for mercury vapor, which is probably more efficient than any one yet devised and which was recently described in *The Journal of the Fr. Inst.* Also, the stop cocks with little liquid air vessels attached are convenient devices for preventing stopcock grease from getting into the main parts of the apparatus.

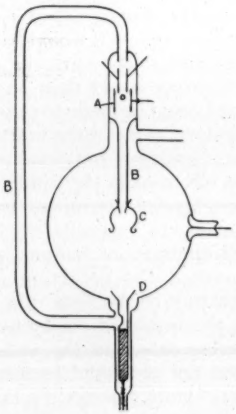
A DEVICE FOR OBTAINING HIGH POTENTIALS.

Fig. 29 represents an apparatus with which, if the fates are kind to me, I hope to realize very high electric potential, possibly of the order of a million volts. One of its features lies in the fact that the body which becomes charged is totally disconnected from all external conductors so that loss by coronas and the like are eliminated. You might think that such an isolated charged body was in the highest degree useless, but of that more anon.

The scheme amounts practically to a water dropper in a vacuum, with the water replaced by a steel ball. The ball falls from a glass tube through an earth-connected metal

tube which it touches as it emerges. Around this tube is a cylinder *A* which can be maintained at say 30,000 volts. The ball receives an induced charge as it leaves the tube and with this it falls down the glass tube *B* into the nickel sphere *C*. It makes contact with this sphere at a little funnel and there gives up its charge to the sphere. Contact with the sphere is broken while it is inside, so that it then falls into

FIG. 29.



the funnel *D* where it hits on a rod of iron and then runs out through a hole into the glass tube *B* where, by a magnetic device, it is carried up to the top of the apparatus and allowed to fall again. In order to prevent the ball from knocking the bottom out of the tube at the point where it falls, the iron rod which it strikes is held suspended in space inside the vacuum, like Mohammed's coffin, by means of a current carrying solenoid outside. The nickel sphere should go on rising in potential, the limit being obtained when the potential is so high that the work required to put an additional element of charge q brought down by the ball onto the sphere, that is the work Vq, is equal to mgh where m is the mass of the ball, g the acceleration due to gravity and h the height of fall.

As you will readily see it is always possible to measure the potential of the sphere by this idea even though nothing is connected to it. All we have to do is to adjust the potential of A and consequently the magnitude of q so that the ball just fails to fall in. For this purpose it is planned to provide an additional ball which is hollow and so has smaller weight. The sort of purpose for which one would use such an apparatus is the creation of very high velocities in electrons, such as would enable us to approximate the conditions obtained in beta rays from radium. By shining ultraviolet light through a quartz window onto the sphere it would be possible to liberate electrons therefrom and thus secure the source of electrons desired. These electrons would then be hurled away from the nickel sphere and could be made to pass through a suitably arranged metal window. One of the matters of investigation would of course be phenomena concerned with the absorption of these high-speed electrons in the window.

Some years ago Mosley attempted to obtain very high potentials by attaching to an insulated conductor placed in a vacuum a small quantity of radium, shielded by a thin casing which prevented the departure of alpha rays but permitted the departure of the beta rays. In this way the thought was that the insulated conductor might charge up to a potential corresponding to the velocity of beta rays. The experiment was not successful because at a potential of the order of 250,000 volts gaseous discharge prevented the potential from rising any further. Two matters favor the present apparatus however, as compared with Mosley's. In the first place we can today produce much better vacua than were produced in Mosley's experiment; and, in the second place the rapidity of charging of the sphere which would be realized under the conditions I have named would be the equivalent of what Mosley would have had if he could have used about 8 grams of radium.

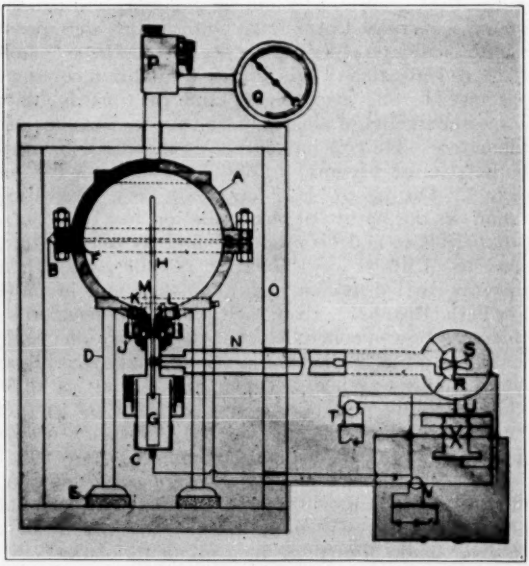
THE VARIATION OF RESIDUAL IONIZATION IN A GAS WITH PRESSURE AS A FUNCTION OF THE ALTITUDE.

The last investigation which I plan to describe to you is one which I undertook under the auspices of the Bartol Foundation with the object of securing data regarding the so-called cosmic radiation. It has been known for a long time

that in a vessel free from radioactive contamination ions are produced at a constant rate of about ten pairs per cubic cm. per second over land. A certain amount of this ionization is known to be due to radium emanation in the atmosphere and to radium in the soil. When, however, measurements are made over the ocean where in the water itself and in the air above it there is a negligible amount of radium content, about 4 ions per c.c. per sec. still make their appearance. Many years ago Prof. McClennan and his students showed that in a vessel of ice situated over Lake Ontario ions were produced at the rate of about 2.6 per c.c. per sec. It has been customary to attribute ionization of this kind to a radiation coming from regions outside our atmosphere, and in 1923 Kohlhorster made measurements of this radiation up to altitudes of 9 or 10 kilometers. He concluded that it increased from about 3 ions per c.c. at sea level to about 80 ions per c.c. at ten kilometers. During the last few years very interesting information on the nature of this radiation has been obtained by Prof. Millikan and his students, first by sending up pilot balloons to altitudes of the order 15 miles and then by experiments carried out on high mountains and in snow fed lakes at high altitudes. From their pilot balloon experiments, Millikan and Bowen concluded that the absorption coefficient of the radiation was much less than that found by Kohlhorster. Happily, the divergence between the values of different observers for this radiation is not so great as to prevent agreement on the conclusion that the absorption coefficient is much larger than for ordinary gamma rays, so that it is possible by suitable shielding of the apparatus to diminish to relative insignificance the true gamma ray part and so disentangle it from the more penetrating part. In 1923 Kohlhorster made absorption measurements of the radiation in Alpine glaciers while Millikan and Otis made absorption measurements with lead at the summit of Pikes Peak. Kohlhorster's data gave an absorption coefficient of 0.25 per meter of water. On the other hand, Millikan and Otis concluded that if there existed any rays of cosmic origin they must be more penetrating than Kohlhorster found, or the intensity of sea level must be less than corresponding to the value two ions per c.c. per sec. which he regarded as the most probable value.

In 1925 Millikan and Cameron by sinking apparatus to various depths in snow fed lakes at high altitudes arrived at the conclusion that there existed a radiation of cosmic origin such as would produce 1.4 ions per c.c. per sec. in the ionization chamber at sea level. Moreover, they concluded that this radiation was of a non-homogeneous type varying

FIG. 30.

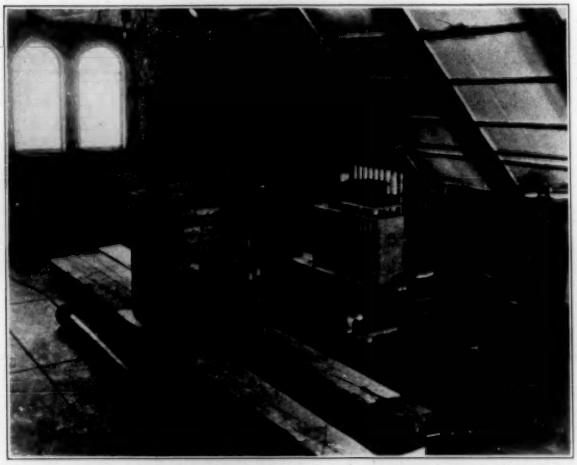


in absorption coefficient from 0.18 to 0.3 per meter of water. Still further measurements have lead them to extend the range of absorption coefficient from 0.1 to 0.25. On the other hand, Hoffman on the basis of Kohlhorster's results found 0.29 ions per c.c. for the ionization at sea level.

Measurements of the residual ionization as a function of the pressure lead to the conclusion that the increase of

ionization per atmosphere diminishes with pressure increase. Such measurements are of interest because the increase of ionization per atmosphere increase at high pressures is independent of the effects of soft radiation emitted from the walls of the vessel as a result of radioactive contamination or even as the result of the action of the primary radiation.

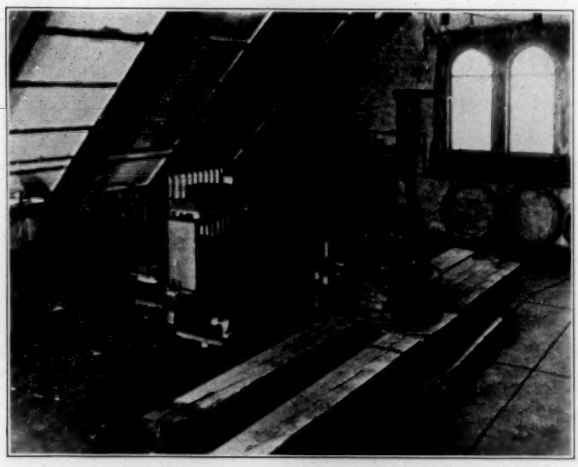
FIG. 31.



While the increase in ionization per atmosphere is not the same thing as the ionization produced in a vessel at one atmosphere, it is closely related to it, and it appears on the basis of plausible assumptions that the least value of the increase of ionization per atmosphere for the whole ionization pressure curve is greater than, or at least equal to, the ionization which would be produced at one atmosphere by the direct and secondary actions of the penetrating radiation in the gas itself. The experiments which I am about to describe were made at the summit of Pikes Peak, at Colorado Springs, and in New Haven. I carted about two tons of apparatus to the top of Pikes Peak and stayed there for a week. Most of the indi-

vidual pieces of the apparatus weighed about 250 lbs. and while theoretically there were laborers about, one could not rely upon getting them when wanted so that most of the time I was hauling those things about myself; and, if you have ever tried this when you have only two-thirds of an atmosphere to breathe, after being accustomed to live at sea level, and have to do it

FIG. 32.

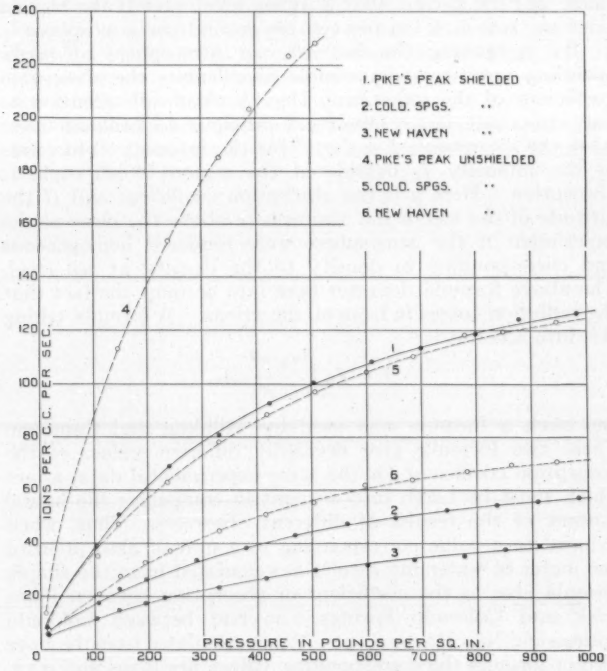


during the first day or two that you get up the mountain, when you feel as sick as a dog, you will know what it means. When I got up the mountain I went to see the grave of a man who had been buried up there and I thought what a beautiful idea that was. After I had been up there a week I decided that I would not even like to be buried there and the comforts of a nice hotel never in my life seemed so welcome to me as they did when I came down that mountain.

Here is the apparatus used (Fig. 30). I must not enter into detail other than to point out the iron sphere A, an inch thick, in which the pressure was blown up by means of high pressure cylinders to about 1,000 lbs. to the sq. inch.

Figs. 31 and 32 are pictures of the apparatus as set up in New Haven. The lead rings serve to surround the sphere and shield out the softer radiations of radioactive origin, and the like. Fig. 33 shows the curves obtained. The upper

FIG. 33.



one was obtained at Pikes Peak when the apparatus was unshielded by the lead. The next lower corresponds to Pikes Peak shielded by lead. The next, dotted curve, corresponds to Colorado Springs unshielded and the next below that corresponds to New Haven unshielded. Finally, the two lowest curves correspond, respectively, to observations taken

at Colorado Springs and New Haven with the apparatus shielded. In the case of two sets of observations taken a month apart the points lay so accurately on the single curve that it was impossible to say which belonged to one set of observations and which to the other. The increase per atmosphere at New Haven, that is at sea level, and at the highest pressure, was 0.16 ion per c.c. per second per atmosphere.

By comparing the increase per atmosphere at corresponding pressure it is possible to calculate the absorption coefficient of the radiation. Here I must call attention to one important fact. Observers previous to Millikan have used the expression $I = I_0 e^{-\mu H}$ for the intensity I, in terms of the intensity I_0 outside of the region of atmospheric absorption. Here μ is the absorption coefficient and H the altitude of the top of the atmosphere above the place of the experiment if the atmosphere were rendered homogeneous and corresponding in density to the density at sea level. The above formula does not take into account the fact that the radiation comes in from all directions. A formula taking this into account is

$$I = I_0 \int_0^\infty \frac{e^{-\mu H x}}{x^2} dx,$$

and such a formula was used by Millikan and Cameron. These two formulæ give decidedly different values of the absorption coefficient for the same experimental data, a fact which must be taken into account in comparing the actual content of the results of different observers. Thus, when reduced to a value corresponding to a unit of absorption of one meter of water my results as calculated from the simple formula give as the coefficient of absorption between Pikes Peak and Colorado Springs 0.39 and between Colorado Springs and New Haven 0.172. When calculated from the more correct formula the corresponding values are 0.305 and 0.12.

There is much that might be said as to the significance of these results, particularly in their relation to the theory of the earth's charge, but the hour is now late and I must forbear.

CONCLUSION

In attempting this very rapid survey of the problems under way at the Bartol Foundation I have naturally had to

omit the discussion of many matters which will immediately occur to specialists on the subject and I hope that any points on which you may desire further enlightenment will be brought out in discussion. I think all of the gentlemen concerned in these experiments are present, and since you have heard enough of my voice I have no doubt that it will be more agreeable in some cases to hear answers from them. I have tried as far as possible to indicate in what way the various experiments have some significance in relation to our search into the fundamentals of truth, and if any of them seem to you rather speculative I can only remind you that it has always been true of science that the visions of today are the realities of tomorrow.

The Seventh Cruise of the Non-Magnetic Yacht "Carnegie." J. A. FLEMING. (*Science*, May 11, 1928.) The Assistant Director of the Department of Terrestrial Magnetism, Carnegie Institution, reports that this vessel left Washington, D. C., on May 1 for a further magnetic and electric survey of the oceans. Already 290,000 miles have been covered by the preceding six cruises. The present one will add 109,000 miles to the total. The proposed route is this: England, Germany, Iceland, Barbados, North Pacific, South Pacific, South Atlantic, Indian and North Atlantic oceans. The voyage will end about September, 1931.

The sailing staff consists of 17 men, while 8 constitute the scientific personnel. The instrumental equipment is much ahead of that carried on the sixth cruise. Magnetic inclination and intensity will be determined by electro-magnetic methods and the atmospheric potential-gradient will be registered photographically. The new work to be carried out includes observations of natural marine electric-currents as well as an extensive program in oceanography both on the physical and the biological side. About a score of scientific organizations in the United States and abroad have furnished either mental or material equipment for the cruise. There can be no doubt that this voyage will not only add to the safety of navigation but will also contribute largely to the knowledge of the earth's magnetism as a whole. Thus a further approach will be made to the solution of a very difficult problem. The activities of the Department of Terrestrial Magnetism directed by Dr. L. A. Bauer form a chapter in scientific progress of which all citizens of the United States may well be proud.

G. F. S.

THE FOUR VARIABLES OF THE VISUAL THRESHOLD.

BY

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IN the investigation of questions relating to lighting, it becomes of importance to measure the capacity of the eye to see; and in performing this measurement, we are confronted with the fact that there are almost as many different ways of evaluating visibility as there are different things to look at. It becomes necessary then, as the first step toward the perhaps impossible task of exhausting this subject, to select a limited series of visual objects for study.

In the present work the selection of this series has been guided by two considerations. The major one of these has been the necessity, in scientific work, of dealing with things which are susceptible of exact description and reproduction. The second consideration has been the technical problem of constructing such visual objects which shall also extend over the widest possible ranges of the variables involved.

The eye is capable, under otherwise favorable conditions, of resolving very small objects. The familiar test-card of the ophthalmologist is an illustration of this. In practice, it is found that two objects may be distinguished when they are separated by as little as one minute of visual angle. In this case, however, as with the letters on the test-card, the objects must be marked off from their background by a high factor in brightness. The white surface of the card reflects perhaps 80 per cent. of the light falling upon it; the ink with which the letters are printed, perhaps 5. The difference, 75, is then about 94 per cent. of the brightness of the card, which, in this case, we may look upon as the general level of brightness to which the eye is exposed.

While these conditions may be held to apply, without great modification, to most of the reading and clerical work which the eyes are called upon to perform, it is otherwise in many cases where vision is of the highest importance.

The best illustration of these conditions is perhaps the appearance of a large object, such as a building, when it is no more than just visible through a fog. As we approach such an object, when it first becomes visible it is seen only in its outlines, within which is included an area of the visual field which is extremely large as compared with the critical letter on the test-card. But on the other hand, the brightness-difference between this area and its background, which makes it visible at all, is slight. The area, in silhouette, appears of a very pale gray, which may be, say, one or two per cent. darker than the surrounding background. As we approach the object, the visual angle increases and at the same time the depth of the layer of intervening fog is reduced with corresponding increases in the contrasts. In consequence, the details of the building come to be visible upon the silhouette, first, the larger ones as the doors and windows, later the shingles, clapboards or bricks as the case may be.

These two extreme conditions for vision, as well as all intermediate stages, may be produced in the laboratory by comparatively simple means,[1] as was the case in the experimental work here to be described. Test-objects (Fig. 1)

FIG. 1.

THE FORM OF THE TEST-OBJECT.

The interval between the dark rectangles is equal to their width and is one-third of their length. When this interval is 1.745 mm., it subtends 1 minute visual angle at the eye, 6 meters distant. The "size" in visual angle is computed upon this basis.

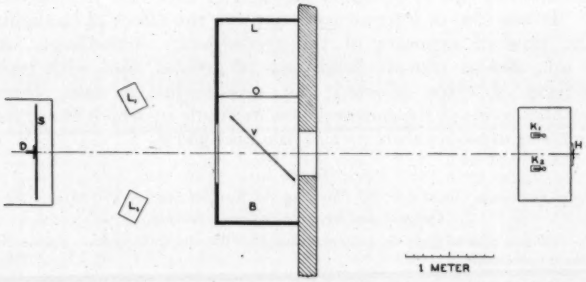
of various sizes were made of the deepest black on white. One of these was placed at the center of a large, white screen *S* (Fig. 2) at six meters distance from the eyes of the subject at *H*. About half way between, a sheet of plate glass *V* is interposed in the line of vision, making an angle of about 45° therewith, in such a way that the subject sees, reflected in

[1] A more detailed description of the technique used is to be found in an earlier communication on this subject in the *Journal of Experimental Psychology*, August, 1927, Vol. X, pp. 350 to 364.

the plate glass and superimposed upon the screen, the image of a large sheet of opal-flashed glass O, illuminated uniformly from behind. Under such conditions, with separate control of the illuminations upon the test-object by means of lamps L_1, L_1, and upon the large diffusing surface o, whose image (the "veil") is seen in the oblique reflector, by lamps at L, it is possible to construct visual objects of various sizes and of all grades of brightness-difference, from the deepest black, through the palest gray to the point of complete extinction.

Designating the brightness of the background of the test-

FIG. 2.



GENERAL ARRANGEMENT OF APPARATUS.

The test object was placed at the center of the screen S, lit by the lamps L_1L_1. The subject's head was steadied by a head-rest at H. A sheet of plate-glass V reflected the image of the opal glass O, lit by a bank of lamps at L. The illumination on S and the brightness of the image of O were independently controllable.

object as s (screen), and that of its black elements as s_0, when the veil is superimposed, these are each seen with an equal brightness, v (veil), added to them. The brightness of the background then becomes $s + v$, that of the figure of the test-object, $s_0 + v$, and the percentage contrast, as expressed here:

$$100\frac{(s+v)-(s_0+v)}{(s+v)} = 100\frac{s-s_0}{s+v}.$$

With a series of test-objects ranging in size from 0.80 to 16.0 minutes visual angle, the percentage contrast was determined at which each test-object was just at the border of visibility, the brightness of the background $(s + v)$, being

maintained at 20 ml. This procedure was repeated at 100 ml. brightness of background, and again at 1 ml. For these three sets of data the time of exposure of the test-object was uniform at 170 σ (thousandths of a second). The test-object (Fig. 1) was mounted centrally on a disc seen at the center of the screen S (Fig. 2). This disc rotated at the rate of 120 revolutions per minute and could be almost instantaneously stopped and started by a magnetic clutch, which in turn was controlled by a switch in the arc of a pendulum. This arrangement made it possible to stop and start the disc with a very short and measurable interval; and the duration of this stoppage is the time of exposure just stated.

It was also of interest to determine the effect of changing the time of exposure of the test-object. Accordingly, at 1 ml., and at 100 ml. brightness of ground, and with test-objects of three selected and representative sizes, three parallel series of measurements were made in which the three times of exposure were 75 σ, 170 σ and 300 σ.

TABLE I.

Mean Percentage Contrast for the Threshold, for Various Sizes of Test-objects (First Column) and for Nine Different Subjects.

The last column gives the geometric mean for the nine individuals. Exposure-time 0.170 second.

Minutes Visual Angle.	Brightness, 100 ml.									
	C.	M.	T.	Cm.	P.	Cl.	K.	W.	B.	Mean.
0.65	70.4	71.7					59.0		67.8	
0.80	24.6	32.7	45.5	56.5	47.6	92.8	26.9	84.0	35.2	44.8
1.17	11.6	9.65	14.8	16.5	13.4	29.8	10.3	28.0	13.7	15.2
1.63	6.50	4.96	9.09	7.68	8.42	13.7	5.91	15.5	6.51	8.13
2.41	3.73	3.20	5.43	4.28	5.21	7.65	3.22	7.95	3.73	4.67
3.95	1.91	1.73	3.51	1.48	1.96	4.86	2.12	3.57	2.39	2.43
7.98	1.33	1.00	1.95	1.41	1.70	2.21	1.15	1.76	1.35	1.50
16.02	1.05	0.87	1.40	1.19	1.16	1.29	0.93	1.36	1.09	1.14

The results of the three size-contrast sets are given in detail, for each of the nine subjects used, in Tables I, II, and III for 100, 20, and 1 ml. respectively. In Tables IV and V are given the results of the time-sets at 100 and at 1 ml. respectively. In these two tables the figures in parentheses are extrapolated or interpolated, as the case may be, using

Lagrange's formula applied to the logarithm of the visual angle and the logarithm of the percentage contrast. This particular procedure was justified by its application to corresponding data in the size-contrast sets, within which the extrapolated data could be checked directly against the empirical.

TABLE II.

Mean Percentage Contrast for the Threshold, for Various Sizes of Test-objects (First Column) and for Nine Different Subjects.

The last column gives the geometric mean for the nine individuals. Exposure-time 0.170 second.

Minutes Visual Angle.	Brightness, 20 ml.									
	C.	M.	T.	L.	P.	H.	K.	W.	B.	Mean.
0.80		89.1	89.0	78.2			62.2		82.8	
0.99	47.0	39.1	50.2	43.8	56.0	57.0	35.3	74.0	44.3	48.5
1.17	26.6	21.1	34.0	27.7	33.2	38.7	22.1	51.4	26.2	30.1
1.35	17.7	15.2	23.9	19.8	23.3	30.5	15.1	32.7	17.3	20.9
1.63	12.6	9.62	16.0	12.4	14.0	23.6	10.7	22.9	11.6	14.1
1.93	9.25	7.13	11.6	8.75	10.4	17.4	7.76	13.4	7.66	9.96
2.41	6.42	4.62	8.37	6.46	7.86	12.3	5.12	9.02	4.76	6.87
3.20	3.93	3.29	6.85	4.02	6.10	9.26	3.96	6.19	3.44	4.92
3.95	3.29	2.54	4.97	3.23	4.33	6.46	3.20	3.92	2.81	3.71
5.67	2.55	1.95	3.50	2.35	3.17	4.20	2.34	2.94	2.13	2.71
7.98	2.07	1.60	2.91	1.90	2.71	2.98	1.81	2.23	1.75	2.16
11.31	1.72	1.38	2.22	1.58	2.30	2.24	1.54	1.84	1.65	1.80
16.02	1.50	1.27	1.85	1.42	1.79	1.96	1.34	1.61	1.51	1.57

TABLE III.

Mean Percentage Contrast for the Threshold, for Various Sizes of Test-objects (First Column) and for Nine Different Subjects.

The last column gives the geometric mean for the nine individuals. Exposure-time 0.170 second.

Minutes Visual Angle.	Brightness, 1 ml.									
	C.	M.	T.	Cm.	P.	H.	K.	W.	B.	Mean.
1.17	78.5	68.8			85.8		70.0		77.0	
1.35	46.3	45.7	68.1	88.2	58.8	75.8	43.5	92.8	46.0	60.3
1.63	33.8	31.4	47.7	56.7	39.7	52.1	27.7	56.9	31.1	40.5
1.93	24.5	19.2	37.4	39.4	26.6	34.0	18.1	42.9	20.9	27.9
2.41	14.7	11.2	23.8	23.9	16.9	23.8	12.8	23.3	11.8	17.2
3.20	9.34	7.27	15.5	13.4	11.3	17.9	7.46	14.7	7.12	10.9
3.95	6.79	4.97	10.6	9.02	7.0	13.0	5.36	8.67	4.89	7.39
5.67	4.05	3.16	6.70	4.85	3.90	6.41	3.42	5.98	3.15	4.43
7.98	2.91	2.38	4.74	3.32	2.92	4.07	2.54	4.19	2.56	3.20
11.31	2.46	1.75	3.46	2.53	2.24	2.95	1.86	3.05	2.04	2.42
16.02	1.89	1.58	2.62	1.98	1.83	2.41	1.60	2.35	1.62	1.95

The relative probable errors[2] of the results stated in Tables I, II, and III are given in Tables I*A*, II*A*, and III*A* respectively, and in an exactly corresponding way. The

TABLE I*A*.

Relative Probable Errors of the Threshold Values Given in Tables I, II, and III.

These are derived in each case from the five separate serial values. The probable error of the mean E_m, last column, is derived from the nine corresponding individual values E, by formula $E_m = 1/N\sqrt{\Sigma E^2}$, in which $N = 9$. The variations due to the systematic differences between the individuals are therefore not included in E_m.

Minutes Visual Angle.	Brightness, 100 ml.									
	C.	M.	T.	Cm.	P.	Cl.	K.	W.	B.	Mean.
0.65	.047	.036					.039		.016	
0.80	.054	.048	.066	.034	.040	.040	.036	.027	.016	.014
1.17	.051	.060	.023	.030	.055	.056	.036	.085	.016	.017
1.63	.034	.026	.060	.031	.046	.056	.026	.043	.019	.013
2.41	.007	.068	.034	.013	.081	.105	.017	.038	.017	.018
3.95	.020	.049	.038	.033	.078	.025	.030	.042	.044	.014
7.98	.017	.021	.018	.021	.032	.058	.026	.027	.023	.010
16.02	.023	.014	.013	.037	.028	.028	.015	.021	.019	.008

TABLE II*A*.

Relative Probable Errors of the Threshold Values Given in Tables I, II, and III.

These are derived in each case from the five separate serial values. The probable error of the mean E_m, last column, is derived from the nine corresponding individual values E, by formula $E_m = 1/N\sqrt{\Sigma E^2}$, in which $N = 9$. The variations due to the systematic differences between the individuals are therefore not included in E_m.

Minutes Visual Angle.	Brightness, 20 ml.									
	C.	M.	T.	L.	P.	H.	K.	W.	B.	Mean.
0.80		.030	.042	.047			.016		.031	
0.99	.041	.092	.076	.047	.087	.044	.056	.036	.060	.021
1.17	.053	.048	.064	.016	.060	.022	.087	.032	.028	.017
1.35	.056	.051	.036	.050	.083	.047	.064	.025	.020	.017
1.63	.055	.030	.039	.053	.044	.049	.044	.032	.044	.015
1.93	.038	.047	.028	.047	.063	.043	.045	.015	.055	.015
2.41	.035	.061	.026	.072	.057	.055	.034	.038	.040	.016
3.20	.020	.044	.044	.038	.031	.036	.038	.035	.050	.013
3.95	.024	.063	.039	.035	.040	.034	.034	.018	.033	.012
5.67	.048	.056	.022	.042	.048	.043	.051	.011	.023	.014
7.98	.049	.055	.038	.026	.048	.016	.020	.028	.023	.012
11.31	.034	.052	.021	.038	.066	.036	.030	.013	.023	.013
16.02	.054	.056	.034	.032	.042	.030	.050	.031	.027	.014

[2] By "relative probable error" is meant the probable error of the mean, divided by the mean. It is therefore the probable error in terms of the mean as unity.

TABLE IIIA.

Relative Probable Errors of the Threshold Values Given in Tables I, II, and III.

These are derived in each case from the five separate serial values. The probable error of the mean E_m, last column, is derived from the nine corresponding individual values E, by formula $E_m = 1/N\sqrt{\Sigma E^2}$, in which $N = 9$. The variations due to the systematic differences between the individuals are therefore not included in E_m.

Minutes Visual Angle.	Brightness, 1 ml.									
	C.	M.	T.	Cm.	P.	H.	K.	W.	B.	Mean.
1.17	.068	.067			.040		.045		.029	
1.35	.047	.096	.041	.031	.035	.039	.050	.020	.037	.016
1.63	.047	.063	.014	.030	.054	.043	.042	.016	.038	.014
1.93	.061	.097	.015	.032	.040	.073	.030	.044	.038	.018
2.41	.040	.097	.045	.057	.035	.099	.059	.054	.037	.021
3.20	.019	.072	.037	.071	.038	.071	.019	.036	.027	.016
3.95	.037	.076	.035	.061	.069	.072	.013	.038	.021	.017
5.67	.034	.061	.041	.048	.044	.044	.034	.046	.008	.014
7.98	.038	.042	.006	.038	.068	.060	.007	.056	.026	.014
11.31	.023	.040	.020	.016	.062	.050	.020	.049	.035	.013
16.02	.017	.032	.017	.028	.038	.006	.020	.046	.021	.009

relative probable errors of the means, last column, are each derived from those in the corresponding line of the table in such a way as not to be augmented by the differences between the individual subjects, since the latter are regarded as systematic and as not affecting the trend of the final result. An idea of the extent of the individual differences may be gained by intercomparison of the results within Tables I, II, III, IV, and V. The random selection of a totally different group of subjects might yield results different from those given, in excess of the uncertainty indicated by the probable errors stated.

The method of serial groups was used in each measurement. Each individual tabulated result represents the average from five series. Thus 2185 series are represented in the tables. Although the series are of variable length, the number of observations in each series averages not far from 50. Thus the results given represent something like 100,000 observations.

TABLE IV.

Mean Percentage Contrast for Three Exposure-times.

Values which have been interpolated or extrapolated are given in parentheses.

Minutes Visual Angle.	Exposure-Time, Seconds.	Brightness, 100 ml.									
		C.	M.	T.	Cm.	P.	Cl.	K.	W.	B.	Mean.
0.80	0.075	37.3	36.4	62.5	73.4	45.4	93.9	34.2	(94.8)	39.9	52.7
	0.170	28.0	27.8	47.4	58.0	37.5	93.3	29.2	(82.0)	31.6	43.6
	0.300	21.8	23.5	41.7	46.4	33.5	89.8	25.5	(67.8)	26.4	37.2
0.99	0.075								55.7		
	0.170								46.9		
	0.300								39.2		
2.41	0.075	3.81	3.34	6.63	5.19	5.40	10.1	3.89	9.08	4.26	5.35
	0.170	3.37	2.82	4.81	4.58	4.72	8.58	3.72	7.13	3.80	4.56
	0.300	3.08	2.74	4.39	3.93	3.97	7.69	3.39	6.15	3.40	4.08
16.02	0.075	1.14	0.95	1.68	1.23	1.42	1.37	1.02	1.55	1.25	1.27
	0.170	1.08	0.85	1.37	1.07	1.32	1.25	0.96	1.37	1.08	1.14
	0.300	0.98	0.71	1.16	1.04	1.20	1.28	0.90	1.24	0.98	1.04

TABLE V.

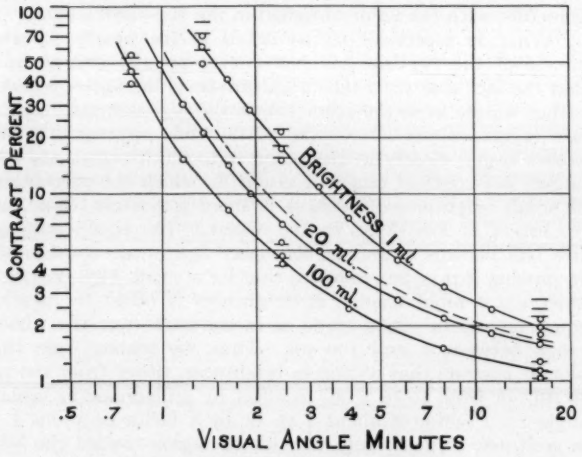
-Mean Percentage Contrast for Three Exposure-times.

Values which have been interpolated or extrapolated are given in parentheses.

Minutes Visual Angle.	Exposure Time, Seconds.	Brightness, 1 ml.									
		C.	M.	T.	Cm.	P.	Cl.	K.	W.	B.	Mean.
1.17	0.075	85.5	81.9			92.9		75.0		86.9	
	0.170	68.2	70.8			88.8		61.4		72.2	
	0.300	58.0	56.8			68.9		52.9		59.1	
1.35	0.075	(60.7)	(56.9)	86.3	(125.2)	(66.8)	(128.2)	(51.8)	(161.4)	(59.2)	81.5
	0.170	(48.4)	(48.1)	65.7	(118.7)	(59.3)	(127.4)	(43.0)	(157.4)	(49.2)	71.0
	0.300	(41.6)	(39.2)	55.7	(96.8)	(48.3)	(98.2)	(37.2)	(115.1)	(40.6)	57.8
1.63	0.075						77.4		91.9		
	0.170						70.3		81.1		
	0.300						56.2		64.4		
2.41	0.075	18.4	16.3	26.0	34.6	21.0	31.0	14.6	33.0	15.8	22.3
	0.170	14.8	12.9	22.1	28.4	15.2	24.3	12.8	25.0	13.3	17.9
	0.300	13.2	11.1	19.4	21.8	14.4	20.8	11.3	22.7	11.2	15.6
16.02	0.075	2.50	2.17	3.71	2.58	2.62	3.64	2.23	3.30	2.31	2.73
	0.170	2.28	1.95	3.32	2.37	2.28	3.15	2.16	3.01	2.03	2.46
	0.300	1.91	1.69	3.06	2.23	2.17	3.04	1.90	2.63	1.82	2.22

The mean values given in the tables are plotted in Fig. 3,[3] in which the three curves drawn in solid lines represent the data from Tables I to III inclusive. The curve in broken lines represents the values for 10 ml., the ordinates having been interpolated by Lagrange's formula from those of the

FIG. 3.



VISUAL ANGLE-CONTRAST RELATION.

The data indicated by the circles on the three curves were taken with an exposure-time of 0.170 sec. Those indicated by the groups of three short horizontal lines were taken at another time with exposure-times of 0.075, 0.170 and 0.300 seconds respectively, from above downward. The group of three circles indicates the result when the three are shifted downward so that the middle one coincides with the original datum plotted on the curve and representing identical conditions.

other three. Each group of three short horizontal lines shows the corresponding values from the time series for 75, 170 and 300 σ respectively, from above downward. The middle line of the three in each group (for 170 σ) should, of course, check with the corresponding datum from the size-contrast set, and does check satisfactorily in four cases out of the six, as shown by the relation of the middle line to the middle

[3] In Figs. 3 to 7, inclusive, the numerals give the actual values of the designated quantities, which are logarithmically plotted throughout.

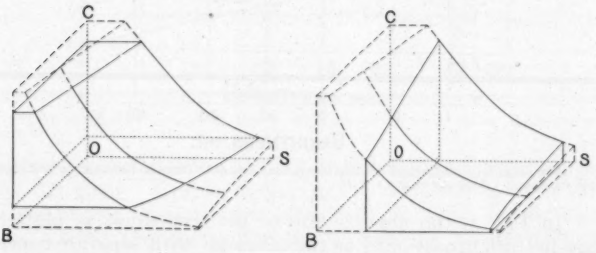
one of the three circles. The reason for the two discrepant values has not been determined. Both occur at the 1 ml. brightness-level, and are part of the last portion of the work done. In any event, the data show consistently the variation to be expected as the duration of exposure is changed between 75 and 300 σ. The three small circles represent the same data, shifted vertically in the plot until the middle one coincides with the value obtained in the size-contrast set.

What is especially to be noted is the nearly parallel course of the two size-contrast curves for 100 and 20 ml., and the fact that for 1 ml. brightness-level the curve departs rather widely from the other two in the high-contrast, small-size region (upper left of the plot), while approaching the others rather closely at the other end, which represents the larger, low-contrast phase of vision, in which the perception of small brightness-differences is more important than the resolution of fine detail in the object. The significance of this will become clearer as the other figures are considered. In passing it may be remarked that for a small, high-contrast object, a tenfold change in brightness is offset by nearly equal factors in visual angle or in contrast, over the whole range between 1 and 100 ml. Thus, by scaling from the plot, it appears that a drop in brightness, either from 100 to 10 ml., or from 10 to 1 ml., is offset by an increase in visual angle by a factor of about 1.45, or by a factor of about 2.3 in contrast. This is only true in the region toward the left of the plot, for objects having visual angles of 1′ to 2′, and seen in contrasts of 10 to 50 per cent. according to circumstances. On the other hand, with objects of 5′ to 16′ visual angle, and seen in contrasts of 2 per cent., more or less, the equivalent factor in visual angle is greater in dropping from 100 to 10 ml. than in the step-down from 10 to 1 ml. The two factors are here 2.1 and 1.45. The corresponding factors in contrast are 1.5 and 1.3 for this region.

It is to be noted here, that since any object is visible by reason of the fact that its brightness (light-intensity) is more or less different from that of its immediate background, there are necessarily not less than two photometric variables involved in any visible object. In the present case, the object is the less of the two, that is, it is darker than its

background, and it is either very small in extent, or only very slightly darker than the ground. The latter may then be considered as representing the brightness-level (or general intensity) to which the eye is exposed and adapted, and is so considered here. Instead of specifying the brightness of the object itself as the second intensity-variable, it has been found convenient to specify it as implied in the percentage contrast, which is the brightness-difference between the ground and the object referred to the former as the base. The brightness of ground and the brightness of object are therefore completely stated by implication in the two variables used:—percentage brightness-difference or contrast; and brightness-level. The former already appears as the ordinate in Fig. 3, while the different brightness-levels are indicated by the three separate curves. These three may be imagined as plotted in different planes in the third (depth) dimension in which case (using logarithm of brightness-level as the corresponding coördinate) the plot comes to look like the

FIG. 4*a*. FIG. 4*b*.

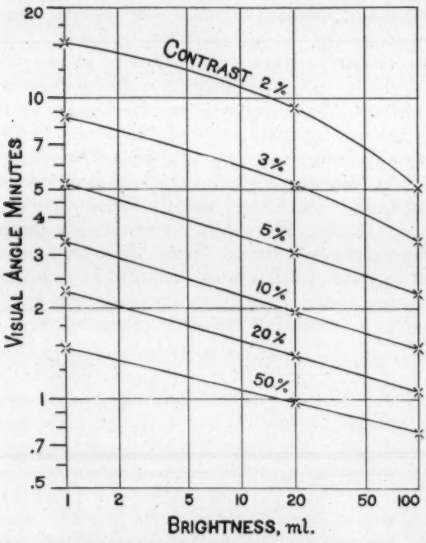


The general form of the surface in which lie the data for 0.170 sec. exposure-time. *a*, indicating the relation to the whole of the curves of Fig. 5. *b*, the same, Fig. 6.

solid figure represented by (full and) broken lines in Figs. 4*a* and 4*b*, the curved surface of which represents the threshold condition for vision in terms of three variables:—visual angle (left to right), percentage contrast (vertically) and brightness-level (from behind forward), for a constant time of exposure of 170 σ. This surface can be conceived as raised or lowered, as the time is decreased to 75 σ or increased

to 300 σ, to the extent indicated by the corresponding data stated in Tables IV and V, and plotted in Fig. 3.

FIG. 5.

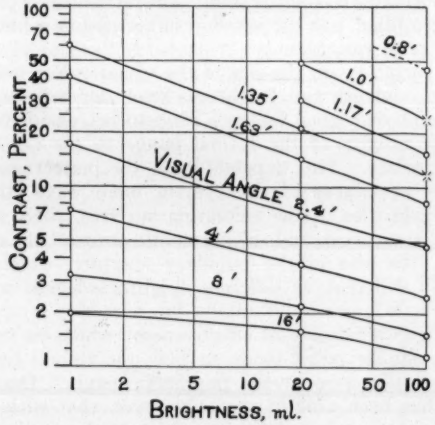


The visual angle-brightness relation for various grades of contrast between the test-object and its ground. Exposure-time 0.170 sec.

In Fig. 5, the angular size of the test-object is plotted, against brightness-level as the abscissa, with separate curves for various grades of contrast. The values plotted are graphically interpolated from Fig. 3, and the separate curves are successive horizontal sections of the curved surface, projected on the horizontal plane, of which the extreme ones are shown in Fig. 4*a* in solid lines. The marked curvature shown in the plot for the contrast-values of 2 and 3 per cent. as opposed to the comparative straightness of the other curves, corresponds to the deviation of the curve for 1 ml. brightness referred to in discussing Fig. 3.

In Fig. 6, the original data are again plotted with brightness-level as the abscissa. The ordinates are the mean contrast values of Tables I, II, and III, and a separate curve is plotted for each size of test-object used. Here the curves are to be looked upon as vertical sections of the

FIG. 6.



Contrast-brightness relation for objects seen under various visual angles. Exposure-time 0.170 sec.

surface, as indicated in Fig. 4*b*, parallel to and projected on the *CB* plane. Corresponding to the deviation of the 1 ml. curve of Fig. 3 from the other two, we note again from Fig. 6 that the curves for the 8′ and the 16′ test-object curve strongly downward, while the other curves are not far from straight.

The range of time used, 75 to 300 σ, was selected as representing what previous work has shown to be about the normal range of pause in the eye-movements in the familiar operation of reading, in which the eyes move rather rapidly and do not linger unduly in fixation upon any point. The aim has been to extend the range of the other three variables of the visual object, contrast, size and brightness-level, and to establish their relationships beyond the range used in

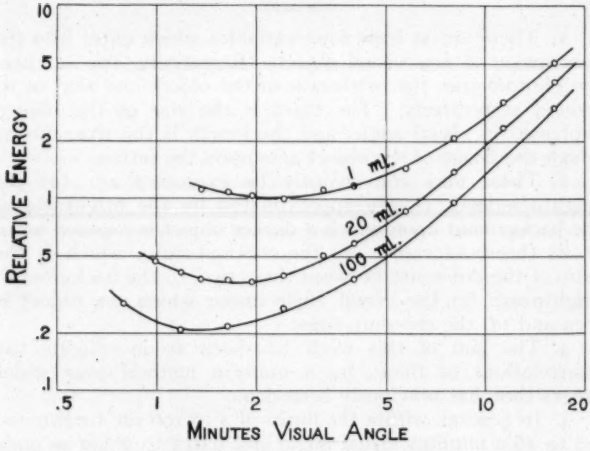
any prior work. All of these variables have been investigated in their various phases, sometimes over wide ranges, as for example, the work of Koenig on visual acuity and on brightness discrimination. Other earlier work has largely been comparatively fragmentary, extending over restricted ranges only, and has been done with various techniques which make the results non-intercomparable. The intermediate gaps have never been filled, nor the whole result stated as a function of three or more variables.

The variations in the size of the visual object, with variations in contrast and brightness-level, depend upon more than one physiological factor. First to be considered is the geometric fidelity of the retinal image to the object from which it arises. This depends upon the perfectness of the refractive apparatus of the eye, in more ways than one. The irregularities of the refracting surfaces, their so-called spherical aberration, and the chromatic errors of the eye play a part. The size of the pupillary aperture, which is undoubtedly different at different brightness-levels, works in two ways: a larger pupil admits the refractive errors of the eye to a greater degree of effectiveness; while, on the other hand, a smaller pupil tends to blur the retinal image by reason of diffraction at the pupillary margin. One of the authors has been able to show, however, that with eyes of normal refractive power, these opposing tendencies just about balance each other, so that the acuity of vision is just about constant, provided the pupillary diameter remains within a range of 2.5 to 4 mm. as observed from the exterior of the eye. As that range represents the usual diameter of the pupil, under ordinary working intensities of light, it is doubtful if we need look for much variation from this cause, except that the pupil tends somewhat, by its variations, to counteract the differences in brightness-level.

At any rate, the degree of blurring of a retinal image which still permits an object to be seen in details separated by as little as one minute of visual angle, must become less and less significant as the extent of the object is increased, up to sixteen times this. In this region a different effect comes into play, namely, the interaction of the retinal end-organs. The fact that decreased brightness-difference may

be compensated by increased size of the retinal image may no longer be explained by the hypothesis that the image is becoming relatively better defined, as in the case of the smallest objects. It is rather to be supposed that the retinal elements reinforce one another, so that the participation of a larger number, as the area increases, accomplishes the same result as before with a smaller stimulation of each element. Such reinforcement could be said to fail completely, if a point were reached at which further increase in the size of the object failed to decrease the contrast necessary for the threshold; but this condition was never reached within the limits of the present experimental range.

FIG. 7.



Energy of the test-object at the threshold, relative to brightness-level, at the three brightness levels used. Exposure-time 0.170 sec.

The relative energies involved at the threshold values of the stimulus are indicated in Fig. 7. The energy is negative, it is to be remarked, since the stimulus is of lower brightness than the field as a whole, and in each curve, the unit plotted is the energy received by the eye, during the exposure time

of 0.170 seconds, from a square element of the background subtending 1 minute angle at the eye, and having the brightness of the screen. The minima of energy estimated from the curves in the figure, for 1, 20 and 100 ml. brightness-level, occur when the visual angle subtended by the object is 2.2, 1.8, and 1.3 minutes respectively, and are 1.00, 0.37 and 0.21 units referred to the respective brightness-levels as just indicated. When referred to a screen brightness of 1 ml. as the unit, these values become 1.00, 7.4 and 21 units respectively. Thus the minimal energy-value at 100 ml. is 21 times that at 1 ml., although relatively to the brightness to which the eye is attuned it is only 1/5 as great at the higher level as it is at the lower.

SUMMARY.

1. There are at least four variables which enter into the description of any visual object. Essentially, two of these are photometric, the brightness of the object and that of its ground respectively. The third is the size of the object, expressed in visual angle, and the fourth is the time during which the image of the object acts upon the retina.

2. These may conveniently be expressed as: (*a*) the brightness-level, closely approximated by the brightness of the background upon which a darker object is exposed when at its threshold value; (*b*) the contrast-ratio, which is the ratio of the difference between these two, to the background-brightness; (*c*) the visual angle under which the object is seen and (*d*) the exposure-time.

3. The aim of this work has been to investigate the interrelations of these, by a uniform method over wider ranges than has previously been done.

4. In general, within the limits of 1 to 100 ml. brightness, 0.8 to 16.0 minutes visual angle and 0.075 to 0.300 seconds exposure-time, measurements of the contrast-ratio necessary for vision at the threshold indicate that these four variables are mutually complementary; that is, a deficiency in one may be compensated by the augmentation of one or more of the other three.

5. The comparatively small advantage of increased brightness in the vision of large, low-contrast objects, obtained by

passing from 1 to 10 ml., would suggest that the optimum brightness for this phase of vision lies at a higher level than for the vision of small, high-contrast objects.

6. Taking the size (visual angle) of the test-stimulus into account, and the contrast-ratio, it is possible to compute relative energy values for the different conditions. At each of the three brightness-levels investigated, it was found that the energy-value passed through a minimum. At 1, 20 and 100 ml. respectively, the minimum occurred when the visual angle was 2.2, 1.8 and 1.3 minutes. The minimum energy is much greater at the higher brightness-levels, but by no means in proportion.

Field Operations of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for the year 1926-27. For the year closing June 30, 1927, the land-survey work was limited to what a single observer in Africa could do in addition to the utilization of opportunities afforded by coöperating organizations. About July 1, 1926, was finished the campaign of taking observations again in a series of repeat-stations in the western continent south of the United States. By this means data were secured on secular and diurnal variation of the magnetic elements. A similar resurvey was undertaken for Africa. Here the conditions of travel have improved since the Department began its work in 1908, yet delays are still frequent and speeds are small. "By the end of June 1927 repeat stations had been reoccupied along the coast of western Africa from Morocco to the mouth of the Congo River, and along such routes to the interior as were available. Among the latter may be mentioned the Senegal River, the Niger River from its source through French Soudan to Cotonou in Dahomey, the Benue River from Garoua in Cameroun to its junction with the Niger River, across northern Nigeria from Kano to Fort Lamy on Lake Tchad, and through French Equatorial Africa and Belgian Congo from Fort Lamy to Boma." Mr. J. E. Sanders, the observer, must have passed an interesting year with his attention directed at one time to the getting of observations at a place on the magnetic equator when the sun passed near the zenith and at another to the unfavorable weather conditions on the Ivory Coast or to his dwindling stock of supplies.

G. F. S.

AIRCRAFT RADIO AND NAVIGATION.

BY

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ABSTRACT.

The essential engineering features of aircraft radio and associated difficulties are discussed. Solutions to these problems are given although no attempt has been made to describe particular equipment. Two outstanding radio aids to aerial navigation are discussed and a new method described whereby these may be made to operate a visual indicator in such a way that it will not only tell the pilot whether he is off his course but which way he is off. A heterodyne beacon having certain remarkable directional properties is described.

THE advent of the modern aircraft with its relatively long cruising range emphasizes the present necessity for radio communication and direction finding, particularly when the plane is handicapped by adverse weather conditions. Radio now plays, and will continue to play, a major rôle in the development of commercial and military aviation since by its very nature it is able to provide the pilot with valuable information relating to facts exterior to his plane. Until within the last two years but comparatively little cross country flying had taken place and many of the present pilots object to the use of radio principally on the ground that it is just another instrument that requires attention. Moreover, many pilots feel that a ship equipped with radio direction finding apparatus is a reflection on their ability as a pilot. This is probably the greatest handicap of aircraft radio today, for the pilots by the very nature of their calling are a race of optimists and if they get into trouble it is always a "rear end collision"! This handicap will clear away of itself within a few years, for radio will offer so much information and mental comfort to the pilot that any preconceived notions he may have had will completely vanish.

The satisfactory operation of radio apparatus on aircraft is fraught with difficulties; human, mechanical, electrical.

The major portion of commercial flights are made with only one man, who must pilot the ship, nurse it mechanically, navigate it and operate the radio. In some cases this works a real hardship on a pilot for he really is a busy man if the air is rough. The additional job of transcribing dots and dashes into intelligence and operating the necessary apparatus may well be too much to expect of a human being. The human being, moreover, becomes fatigued mentally very rapidly due to the incessant din of the engines and after a few hours any mental work not of second nature is nearly impossible. All this brings out the necessity for striving toward the greatest simplicity of operation possible. No controls should be incorporated in the radio equipment save a minimum number of switches and perhaps one adjustment if this is absolutely necessary. Complicated equipment is worse than useless, in particular if it needs attention in the air.

It is the purpose of this paper to point out the major technical features of aircraft radio and indicate so far as possible how the major difficulties may be overcome. No attempt will be made to discuss the radio equipment itself at this time.

ANTENNA SYSTEM.

The preferred antenna on aircraft is the so-called trailing wire antenna. This type of antenna has an advantage over fixed antenna in that the antenna resistance is for the most part radiation resistance. Moreover, the length of the antenna is readily changed by reeling in or out the antenna, thus tuning this system and eliminating one tuned circuit in the transmitter. The trailing antenna is usually worked against the bonded metal framework of the aircraft which serves as the counterpoise or "ground." This, in general, is formed by bonding all metal parts of the ship together and even providing conductors throughout the wing sections should these happen to be made of wood and fabric. It is doubly necessary to install the bonding well and carefully for not only does this improve the effectiveness of the antenna system but is the best fire insurance possible since this precludes sparking at points where gasoline vapor is liable to be found. The gases discharged from the exhaust of the engine are highly charged so the aircraft is constantly accumu-

lating a charge of opposite sign to that of the exhaust gases which on contact with a properly charged cloud may cause small sparks which make their presence known by a peculiar type of "static."

One of the major disadvantages of the trailing wire antenna has been that it constantly swings and thus its apparent capacity changes constantly. In the earlier days of the spark this constant swinging was not a problem but with the advent of C.W. it becomes a real difficulty. If a self-oscillating transmitter or receiver is used which is coupled directly to the antenna it is obvious that a shift in antenna capacity (due to swinging) will alter the frequency of the oscillator thus shifting the beat note about and making it nearly impossible to read. This difficulty has led to the rather wide adoption of I.C.W. on aircraft since a certain amount of periodic detuning can be tolerated. There is no fundamental reason for this procedure, however, since the difficulty may easily be eliminated in the transmitter by the use of a master oscillator operating into a properly balanced power amplifier, which in turn feeds the antenna. A correct balance of the power amplifier ensures no reaction of the plate or output circuit on the grid or master oscillator circuit. The difficulty in the receiver is overcome by the use of a coupling tube which effectively cuts out the reaction of the antenna on the local oscillator. There is no outstanding difficulty in the way of proper antenna installation but the position of the antenna reel and fair lead should be so placed that there is little localized capacity between these elements and the frame of the ship.

DIRECTIONAL PROPERTIES.

The peculiar physical arrangement of the trailing wire antenna in conjunction with the metal parts of the ship used as a counterpoise gives rise to certain directional characteristics. In general transmission and reception are accomplished most easily in a forward direction whereas if a radio compass bearing be taken on an aircraft flying at high altitude the apparent bearing is to the rear of the true plane position. This deviation is unimportant so long as the aircraft altitude is less than 2,000 ft. and may be corrected for if its altitude is known.

POWER SOURCE.

Air fans for driving radio generators are now available that have excellent regulation and load characteristics but these are usually attached to a generator far larger than necessary. It must be remembered that an air driven generator is located in a blast of cold air traveling at least 80 miles per hour and since the rating of a machine is limited only by the amount of heat that can be dissipated it would appear that if suitable ventilating ducts were provided the power output per pound of our present generators could be quadrupled.

Air driven generators offer the advantage of operating in a glide should the engine fail but it should be pointed out that for every pound of head resistance offered by a generator fan about 7 pounds is lost in pay load so that even in a small installation the loss in pay load may amount to 60 pounds.

By directly connecting the generator to the engine the advantage of radio operation during gliding periods is lost but the head resistance is reduced to nil and the pay load only reduced by the weight of the generator. A careful consideration of these facts seem to indicate that modern tendencies may be incorrect and need revision.

RADIO TRANSMITTER AND RECEIVERS.

A discussion of this phase of the subject at the present time is impossible and will be dismissed with a statement of the major requirements which must be met.

By far the most important requirement of aircraft equipment is simplicity in operation. If radio in aircraft is to rapidly come into its own the operation of the equipment must be made easy. More than one adjustment in either the transmitter or receiver cannot be tolerated. The apparatus must be light yet rugged; the volume taken up must be small yet the equipment must be electrically efficient. Vibration effects must be reduced to a minimum and the effect of the swinging antenna on the frequency of the transmitter or receiver must be nil. A satisfactory aircraft design requires the highest type of radio skill and more attention must be paid to the special requirements in the future.

IGNITION INTERFERENCE.

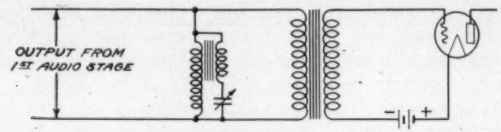
By far the greatest difficulty encountered in aircraft work is interference from ignition apparatus. This interference is continuous and often so great that the tubes are at least partially paralyzed. No simple solution save that of complete shielding is possible. Complete shielding of magnetos, leads and plugs together with any switch leads from the magneto will solve this difficult problem but there is much inertia to be overcome among engine builders and aircraft designers so this particular solution is probably a few years distant. Various makeshift cures have been devised, all based on the idea that if oscillations in the lead wires were suppressed, the desired result would be accomplished. As a matter of fact none of them succeed in doing this and even if they should, the problem would not be solved since the pulse sent out by the magneto shock excites any oscillating circuit in the vicinity and one is as nearly as bad off as one was originally. The pulse sent out by the magneto acts much like static and it is therefore obvious that attempts to shield the receiver are foolish and show a failure to understand the underlying action. Not much gain is made by partial shielding so that unless a complete job is done it seems to be a waste of time.

Experience shows that ignition interference for a given type of installation cannot be foretold. Apparently, very poor ignition installations which to all appearances, should produce a great deal of interference are comparatively quiet while others are noisy. In some cases interference or excessive static clicks have been traced to true static sparks on the ship caused by the charging up of the ship due to the ionized exhaust gases.

Surprisingly enough the noise level on an aircraft in the average unshielded installation is so high that ordinary static is very seldom troublesome. The reason for this is that electrical noise level and engine din are so great that no signal less than approximately 1 volt applied to the phones is capable of being continuously read. Few static clicks exceed this limit unless the plane is very near the storm. The real limitation on reception at the present time therefore is the limitation imposed by the ignition. When C.W. or

I.C.W. of a certain predetermined frequency is made use of there is one method for reducing the interference to signal ratio which is sound theoretically and practically. This

FIG. 1.



Tuned audio stage.

method, shown in Fig. 1 is to provide a tuned audio stage which will respond to the audio heterodyne beat note or the modulation frequency. Any single pulse from the magneto will not communicate sufficient energy to the audio frequency oscillating circuit to shock excite the tuned stage into oscillation but a series of pulses of the correct frequency (the incoming signal) will set it in oscillation. Thus, the signal due to the ignition can be made small while the incoming signal may be maintained. Care must be exercised to keep regeneration to a point where the audio amplifier will not ring, for in some cases transmission may be slowed up due to persistance of the signal.

Recently an improved electro mechanical coupling device employing a tuned reed has been developed that has many valuable features not possessed by an electrically tuned unit. Such a coupling unit may be made extraordinarily selective to frequency without the attendant difficulties of electrical instability. These units have largely replaced the electrically tuned transformers indicated in the diagrams.

DIRECTION FINDING.

By far the most valuable use of radio on aircraft is its use as a direction and course finding agency. The simple coil radio compass and its modified form the Bellini Tosi have proven of great value on land and on shipboard. In the average airplane these methods are totally unsuitable since they require swinging the ship or goniometer coil till a minimum is located. This procedure is not practical nor is

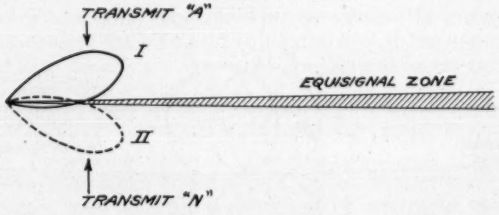
it in general feasible to request compass stations on the ground to give the ship its position. Directional information must be immediately available on the aircraft without recourse to transmission. To this requirement is added that of simplicity of operation and light equipment on the plane.

There appear to be two general methods that satisfy the requirements. One is the so-called radio beacon and the other is a homing method making use of equisignal receiving system which indicates when the ship is headed for the home station.

RADIO BEACON.

The radio beacon is perhaps the better known and was the system used in the Hawaiian flights. The great advantage of this system is that no special equipment whatever is needed on the aircraft. A simple non-oscillating receiver tuned to the beacon frequency and a moderately good pair of ears is all that is necessary.

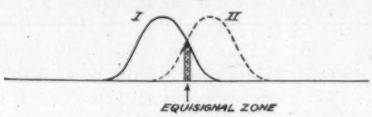
FIG. 2.



The operation of this method in the preliminary and present stage depends on the physiological fact that the human ear is able to judge with great accuracy the equality of intensity of two similar tones when they are sounded successively and close together. In practice it has been found convenient to arrange the signals so that they interlock and if strict equality of the two signals obtain, one continuous signal or dash is heard. In case the intensity of one signal is stronger its characteristic code letter is distinguished against the weaker as a background. The predominance of one or the other informs the pilot as to which way he should bear to bring his ship back on the course. To accomplish

this result two directive systems, usually simple coil antennas are arranged in such a manner that the predetermined aircraft course lies along the radius vector of the polar energy

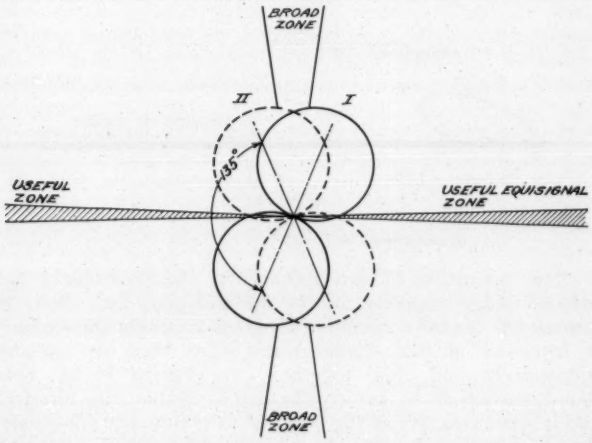
FIG. 3.



Signal observed on plane flying perpendicular to radius vector in Fig. 2.

distribution curve where the change in intensity changes rapidly with angle. Consider the ideal as illustrated in Fig. 2. One directive system radiates energy into space as indicated by the solid polar curve. Another transmitter is adjusted to

FIG. 4.



radiate as indicated by the dotted curve. A plane flying across the radius vector as shown would hear signals as indicated in Fig. 3. As the ship proceeds the signal from system I increases through a maximum and drops off; mean-

time system II is increasing and there will be some point "*E*" where the intensity of the received signals will be equal. This region is known as the equisignal zone and is usually very narrow.

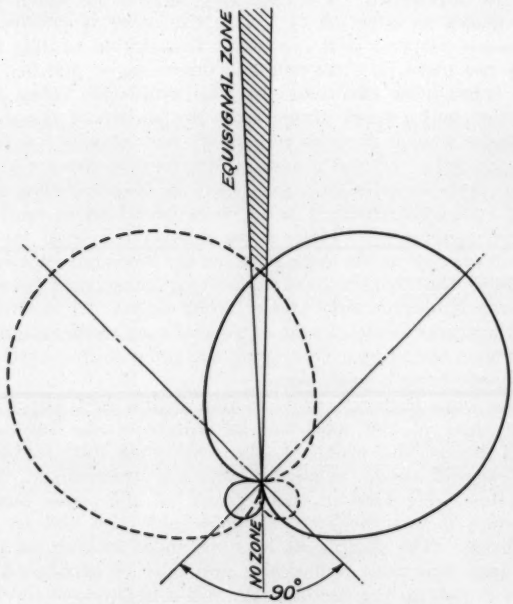
At frequencies available for beacon work in this country an energy distribution curve of the type shown in Fig. 2 is next to impossible. A simple loop system in which each loop makes an angle of 135° with the other is satisfactory for many purposes and particular installation of this type using two loops 60 x 240 feet and operating at 300 kcs. has been found quite effective. In this installation using aural reception and a spark transmitter the widths of the useful equisignal zone at 20 miles was but 75 feet while at 200 miles it was 3 miles. A polar energy distribution curve for this system is indicated in Fig. 4. It will be observed that there are 4 equisignal zones, 2 being very broad zones and two narrow useful ones. There is no particular reason for the selection of 135° as the angle between the loops but experience has shown that this is a good engineering compromise between a narrow equisignal zone and a strong signal. It is obvious that the nearer one works the equisignal zone to the minimum of the loop the sharper the signal, the price of an excessively sharp zone being a weak signal.

The loops used on the Hawaiian flights were effectively at an angle of 120° and the navigators of the successful flights report the width of the equisignal zone to be 3½ miles in mid ocean using a 2kw. tube transmitter. The navigators were loud in their praise of the radio beacon and state it was the greatest single aid they had on the expedition. The sharp zone at 1,000 miles making use of a 120° angle was most remarkable and may be attributed for the most part to the use of C.W. and a heterodyne receiver which would be expected to sharpen the equisignal zone. It is unfortunate that these systems are bidirectional and an 180° error therefore possible. This difficulty has been overcome by combining an antenna effect with the loop effect and shifting the angle of the two directive systems so that they are approximately 90° apart instead of 135°. This is shown clearly in Fig. 5 and offers many advantages. A system of this type has been tried out which was capable of

rotation and it proved to be a possible and practical extension of the usual equisignal scheme.

Any of the systems just discussed may be adapted to a visual indication scheme in place of aural methods. Some sacrifice in range must be expected since the operation of the

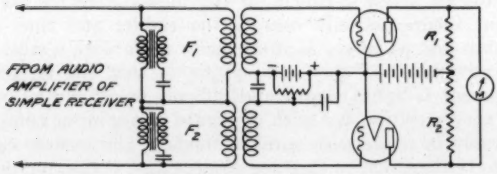
FIG. 5.



device near the noise and ignition level will necessarily be more erratic than the human ear. Such an indicator has been developed recently. The transmitter is so modified that a directional radiator is supplied with modulated high frequency of some convenient low audible frequency. The companion directional radiator is supplied with high fre-

quency modulated at some other low audio frequency not too near the original in frequency and not a harmonic of it. On the aircraft a simple non-oscillating receiver is used to the amplifiers of which are connected in series two audio tuned coupling units as previously described. The secondaries of these coupling units lead to the grids of two vacuum tubes

FIG. 6.



Audio selector and bridge.

incorporated into a bridge circuit as shown in Fig. 6. The indicator "*M*" is a sensitive D.C. microammeter with a zero center. To operate the device the antenna is disconnected and the bridge balanced, bringing the indicating microammeter to the center of the scale, by properly adjusting the bias on the bridge tubes. The bias on the bridge tubes is usually maintained quite large since the deflection of the indicator depends on the curvature of the characteristic at the point of operation, when an A.C. is applied to the grid. The operation of the system is as follows. The H.F. carrier is received and rectified by the detector as usual and the A.C. modulation frequencies amplified by the audio frequency amplifier. This is fed into the two tuned coupling units which exercise a selective frequency action impressing an A.C. on the grid of the bridge tubes the amplitude of which depending on the amplitude of the received modulation frequencies. On the equisignal zone the potential impressed on the grids of the bridge tubes are the same substantially and the balance of the bridge is undisturbed provided tubes of nearly the same characteristics are selected. However, if one modulated frequency becomes greater in amplitude the potentials on the grids change and the bridge is unbalanced causing the indi-

cator to move one way whereas if the other modulated frequency predominates the bridge will be unbalanced the other way causing a reverse deflection. To an observer in the plane the indicator can be arranged therefore to indicate center when on the course and right or left when off the course to right or left. It is obvious that the situation is reversed going away from the beacon. The system may be extended to a red, white and green light system by the addition of a few contacts to the indicator or in the not distant future actually operate the rudder and thus steer the ship just as surely as if the radio wave were a steel rail. The advantage of this new system is that the additional equipment is light, rugged and difficult to get out of order. It is very sensitive and with moderate power input compares favorably in range with aural methods. This system can of course be extended to the case of a rotating equisignal device and the time from a non-directional reference signal to the time that the indicator goes through zero gives the azimuth of the plane from the station provided of course that the period of rotation is known.

There is much to be said for the beacon system since it is exceptionally simple in operation in the aircraft. The ground equipment is relatively simple and should require no special attention. Recent tests of the Bureau of Standards have shown that at night the equisignal zone over mountainous country jumps around. This is very unfortunate but there is reason to believe that this variation will be very small over level country and over water.

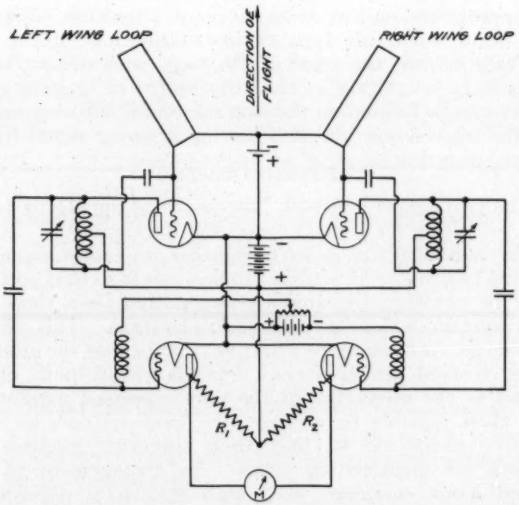
HOMING BEACON.

A homing indicator has been developed recently which appears to have considerable application at the present time. This device serves only as a homing device and will keep aircraft headed always toward some fixed non-directive radio station such as a broadcast station provided the indications of the meter are followed. By listening in on the set the pilot can pick up the broadcast or other station located in the city to which he wishes to fly. The indicator will then guide him toward the station selected. This system in common with the radio beacon not only tells the pilot when he is

headed for his goal but also tells him which way he is off his course. This latter consideration is of some importance since constantly swinging a plane to determine which side of a minimum or maximum one is flying, is a great trouble and few pilots will go to the extra trouble unless they are actually lost.

The homing system makes use of two crossed loops or other directional absorbers working into a double amplifier

FIG. 7.



and bridge arrangement. The two loops usually make an angle of about 135° with each other, much as in the beacon just described. The loops may be mounted one on either wing, the leading edge usually being outward in order to keep ignition difficulties to a minimum. The operation of this system is not greatly different from that described under the indicating beacon. The electrical connections are given in Fig. 7. The two loops are tuned simultaneously to the incoming

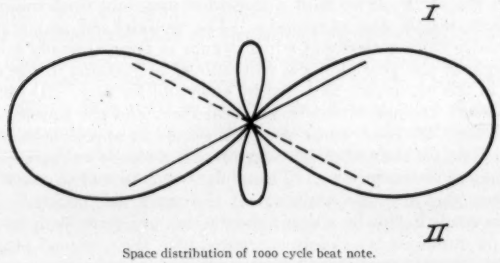
wave by the variable condenser. Each loop feeds into a radio frequency amplifier which in turn feeds in the bridge arrangement. It will be noted that the rectification of the high frequency controls the plate current of the bridge tubes and not the audio frequency as before. An inspection of the set up shows that both loops are operating well off their maximum and when the plane is pointing toward the transmitter swinging to the left increases the voltage impressed on the right coil and decreases the voltage impressed on the left coil. This shift causes the bridge balance to be upset and the appropriate indication takes place. Ignition difficulties may occur with this type of installation but if the ship structure permits the angle of the loops with respect to the ship can be so shifted so that the source of ignition interference can be located on the loop minimum reducing materially the interference and still leaving a strong signal from a forward direction.

HETERODYNE BEACON.

The two general systems just described appear to be the most promising for general usage and development. Should greater necessity for radio navigation arise and numerous rotating beacons be located at suitable points so that positions could be obtained by simple triangulation then there is a third system which deserves consideration. This system depends on the heterodyne principle, that is, that the intensity of the received beat frequency depends within limits on the *product* of the intensities of the two impressed oscillations. It is then possible to arrange two loop systems or other directive radiations so that their intensity minima and maxima are displaced in space. An arrangement of two crossed loops energized with high frequency differing in frequency by 1,000 cycles, say, yields a space distribution of the heterodyne beat intensity of 1,000 cycles as shown in the Fig. 8. The reason for the occurrence of two minima is that the received signal is proportional to the product of the two intensities then if either is reduced to zero their product will be zero. One of the prime requirements of this setup is that the two directive systems must not be coupled in any manner. For use in a rotating beacon the double sharp zero signal on either side of a narrow maxima is precisely the

type of variation most suitable for timing. As has been indicated the procedure with this type of rotating beacon is to send out a non-directional timing signal when the sharp maxima is directed north. At this instant the directive

FIG. 8.



Space distribution of 1000 cycle beat note.

system is rotated clockwise at such a speed that it makes one revolution per minute. The observer starts a stop watch or other device on hearing the timing signal and then listens for the first sharp maxima at which time he stops the watch. The angle through which the hand has moved gives the azimuth of the observer from the transmitter. This may be in 180° error and it is essential to know the general direction of the station from the observer. This chance for error may be eliminated by combining an antenna with each loop. So far this has not been done and it is not known what difficulties may be encountered. Certain other aspects of this fundamental heterodyne space distribution principle are now under consideration.

The possibilities of radio as applied to aircraft are unlimited and much remains to be done. Satisfactory communication and position finding are accomplished facts and need only development and experience to make them foolproof and perfectly satisfactory. The systems and methods described in this paper should be taken as only indicative of the possibilities in this special field.

Observations on Earth Currents in Australia. Annual report of the Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, 1926–27. The Department maintains an observatory at Watheroo in Western Australia. Here systematic records of the magnetic elements are made and in addition differences in earth potentials are registered automatically. From the earth currents in a east-west line only confirmation of previous results was obtained. "The well-defined maximum in the north-south component which occurs at approximately midday throughout the year shows a well-defined progression in the exact time of the maximum, as noted by Gish and Rooney. In January this occurs at approximately 11^h local time, and the time steadily grows later till June, when the peak occurs at approximately 14^h. From June till the end of the year there is a steady retrogression in the time of the occurrence. There might thus be a close connection between this and the variation of the sun's declination." The studies made in this far distant observatory are quite likely to shed light on questions not closely connected with their original purpose, for the Director remarks: "Another line of investigation in which we have been of assistance concerns the feasibility of determining geological formations of scientific interest and of economic value by means of magnetic and electric methods. The experience gained by Gish and Rooney in the resistivity-surveys of the soil at Watheroo, Western Australia, and at the Ebro Observatory, Tortosa, Spain, has suggested methods and furnished data of considerable interest to geophysicists and geologists."

G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

TYPE TESTING OF COMMERCIAL AIRPLANE ENGINES.

THE Air Commerce regulations of the Department of Commerce provide that all airplanes considered as airworthy and permitted to engage in interstate air commerce must contain power plants approved and rated by the Department. The engines first used in commercial planes were those designed and built for military purposes and these engines are known to be safe because they have been thoroughly tested by the Army or the Navy. However, many aviation engines are now being built which are intended primarily for commercial rather than for military use and each new type of commercial airplane engine must pass certain tests before it can be certified as airworthy by the Director of Commercial Aeronautics.

These type tests are made at the Bureau of Standards or, in exceptional cases, at the manufacturer's plant under the supervision of engineers from the Bureau. Before it will be accepted for test the engine must have been run by the manufacturer for at least 25 hours and a log of this run must be submitted with the engine. The Department's present test requirements include (1) a 50-hour endurance test to be run in 10 five-hour periods, (2) full-throttle runs to determine the power developed at speeds ranging from 75 to 110 per cent. of normal speed, and (3) an actual service test of the engine installed in an airplane. As the engines thus far submitted are air-cooled, they have been mounted on a torque stand for the endurance test and power runs. Suitably designed propellers absorb the power and at the same time produce sufficient airblast to cool the cylinders. As soon as the necessary equipment can be installed these tests will be made in the laboratory; using an electric dynamometer to absorb the power and an 80 horsepower blower to supply the high-velocity air-stream required to cool the engine.

The following fixed radial air-cooled airplane engines have been tested or are now under test:

* Communicated by the Director.

Warner 7-cylinder of Detroit, Michigan.
Kinner 5-cylinder of Glendale, California.
Comet 7-cylinder of Oakland, California.
Szekely 3-cylinder of Holland, Michigan.

The following fixed radial air-cooled airplane engines are scheduled for test during the next two months in the order named:

Velie 5-cylinder of Moline, Illinois.
Floco 7-cylinder of Los Angeles, California.
Menasco-Salmson 9-cylinder of Beverly Hills, California.

Each power plant is considered on its own merits and there are no standard requirements as to weight per horsepower, fuel consumption per horsepower hour or oil consumption per horsepower hour. Sound design, adequate materials, good workmanship, and reliable performance of the engine and its accessories are demanded. In accordance with Army and Navy practice, the endurance test consists of nine periods (45 hours) at rated speed and load and one period (5 hours) at 10 per cent overload.

Although the testing of commercial airplane engines has only recently been undertaken, the automotive section of the bureau has been studying the performance of aircraft power plants for over ten years. As early as 1913 an electric dynamometer was installed at the bureau and tests were made on two Reneault airplane engines for the Signal Corps of the United States Army. By 1917 the addition of a 400 horsepower dynamometer had provided for the laboratory testing of the most powerful aircraft engines then known and torque stands were installed for running service and endurance tests of all sizes and types of engine. The first experimental Liberty engine was delivered at the bureau on July 3, 1917, just 21 days after its design was approved and was tested both on the dynamometer and on the torque stand. This engine is now on exhibition at the Smithsonian Institution.

There was then designed and built the first complete laboratory for the study of aircraft engine performance under the conditions of temperature and pressure which exist at high altitudes. The Altitude Laboratory consists of a re-

inforced concrete room capable of withstanding an external pressure of a ton per square foot. This room contains refrigerating coils, a stand for mounting the engine, connections for supplying metered quantities of air, fuel, oil and water to the engine, for taking away the exhaust gases and for measuring the temperatures and pressures in and about the engine. The engine, mounted in the chamber, is connected, by means of a shaft carried through the wall, to an electric dynamometer for controlling the load and measuring the power developed. All necessary measurements in fact are made by means of instruments outside the test room. With this equipment the pressure at the intake and the exhaust as well as the temperature, pressure and humidity of the air entering the carburetor and surrounding the engine are controlled. The engine can thus be run at the ground under the precise conditions which might be encountered at any altitude up to 30,000 feet and all features of its behavior under these conditions are accurately measured. Before this equipment was available, tests of the Liberty engine and of superchargers were made on the top of Pikes Peak although the equipment which could be transported by truck to the altitude of 14,000 feet permitted only the crudest kind of test.

In the past ten years, all the important American-made water-cooled engines and several foreign makes have been subjected to comprehensive tests in the Altitude Laboratory and in many cases important defects have been discovered and remedied because of the ability to make very accurate measurements under the extreme conditions of pressure and temperature encountered in flight. Tests of the Liberty 12 engine and of the Curtiss D-12 engine under ideal supercharging conditions (that is, with air at sea-level pressure supplied to the carburetor while the pressure at the exhaust and around the engine was reduced to correspond with that existing at various altitudes) were undertaken a few years ago at the request of the National Advisory Committee for Aeronautics. These tests and tests of the Curtiss D-12 engine equipped with a geared centrifugal supercharger which were made for the United States Army Air Corps showed the need of additional exhauster and air cooling capacity. Accordingly, larger vacuum pumps and a complete new cooling system have been installed.

There is needed at the present time a corresponding Altitude Laboratory for the accurate testing of large air-cooled aircraft engines under the conditions encountered in flight. Such a laboratory will differ from the present installation chiefly in having provision within the evacuated engine chamber for the circulation of air at the high velocity required for efficient engine cooling.

TWENTY-FIRST NATIONAL CONFERENCE ON WEIGHTS AND MEASURES.

ALTHOUGH the Bureau of Standards has no regulatory power it has played an important part in the movement for greater uniformity in weights and measures laws and regulations throughout the United States. One of the ways in which this has been accomplished is by holding each year at the Bureau a national conference composed of weights and measures officials from all over the country, manufacturers, and others interested in weights and measures matters.

At this conference papers are presented dealing with every phase of weights and measures enforcement, practical solutions to common problems are worked out, and reports of progress are presented. The conference is always well attended, although attendance is entirely voluntary. However, the majority of the state governments have long recognized the desirability of being represented and the same applies to manufacturers of weighing and measuring appliances.

The twenty-first conference will be held on May 22 to 25. The tentative program, which contains much of interest, is as follows:

TUESDAY, MAY 22.

Morning Session, 10 o'clock

Note: Sessions on this day will be held at the Bureau of Standards.

Registration of delegates and guests.

Address of the president of the conference, Dr. George K. Burgess, Director, Bureau of Standards.

Reports of State delegates.

Reports of Representatives of State associations of weights and measures officials.

Luncheon at the Bureau.

Afternoon Session 2 o'clock

Report of the secretary of the conference.

Bureau of Standards investigation on transmission drive for taximeters; Ralph W. Smith, Bureau of Standards.

A new scale-testing device; Warren Hem, Engineer, Toledo Scale Company.

Installation of Bureau of Standards master scale; H. M. Roeser, Bureau of Standards.

New equipment for testing heavy-capacity scales in New Jersey; Joseph G. Rogers, assistant superintendent, Department of Weights and Measures, State of New Jersey.

Proposed amendment to section 21a of model State law.

WEDNESDAY, MAY 23.

Morning Session, 10 o'clock

Note: This session of the conference will be held at the House Office Building, adjacent to the Capitol.

Hearing on H. R. 7208, "A bill to regulate and control the manufacture, sale, and use of weights and measures and weighing and measuring devices for use or used in trade and commerce, and for other purposes."

Acting under instructions from the Twentieth National Conference on Weights and Measures, a special conference committee, appointed for this purpose, secured the introduction of this bill into the present Congress.

Afternoon Session, 2 o'clock

Note: This session of the conference will be held in the 10th floor ball room of the Raleigh Hotel, Pennsylvania Avenue at 12th Street.

Supervision of gas and electric meters in Texas; W. T. Henrichson, meter inspector, division of weights and measures, State of Texas.

Some comments on coöperation among weights and measures officials; J. H. Meek, director, division of markets, State of Virginia.

Promotion of interest in weights and measures supervision by essay contests among school children; James J. Dawson, inspector of standards, State of Massachusetts.

A periodical on weights and measures by the sealers' association; A. W. Corwin, sealer of weights and measures, County of Allegany, New York, and editor, Weights and Measures News.

Report of special committee on constitution and by-laws.

General consideration of subjects of interest and questions brought up for discussion by city and county officials.

At this time officials should bring before the conference for consideration all subjects of interest to them not elsewhere listed on the program.

All officials are urged to participate in these discussions in order to make them of maximum value.

Appointment of committees.

THURSDAY, MAY 24.

Morning Session, 10 o'clock

Note: Sessions on this day will be held at the Bureau of Standards.

Weights and measures aspects of chain-store operation; A representative of The Great Atlantic and Pacific Tea Company.

Report of Committee on Specifications and Tolerances on Specifications and Tolerances for Grease-Dispensing Devices.

Address, Hon. Herbert Hoover, Secretary of Commerce.

The business man and the weights and measures official; Edward L. Greene, general manager, National Better Business Bureau, Inc.

The development of industry; A. Bousfield, chief engineer, E. & T. Fairbanks & Company.

Official photograph.

Luncheon at the Bureau.

Afternoon Session, 2 o'clock

Testing of gasoline meters in the field; William Foster, sealer of weights and measures, City of Springfield, Mass.; Theo. A. Seraphin, district supervisor of weights and measures, city and county of Philadelphia, Pa.; John H. Stephenson, sealer of weights and measures, City of Rochester, N. Y.

Testing of gasoline meters in the factory (several manufacturers of gasoline meters will speak on this subject).

Report of committee on specifications and tolerances on the specifications and tolerances for liquid-measuring devices tentatively adopted in 1927.

Report of committee on specifications and tolerances on the tentative specifications and tolerances for lubricating-oil bottles.

FRIDAY, MAY 25.

Morning Session, 9:30 o'clock

Note: This session of the conference will be held in the 10th floor ball room of the Raleigh Hotel, Pennsylvania Avenue at 12th Street.

Report of committee on specifications and tolerances on minor changes in codes of specifications and tolerances formerly adopted.

Flood conditions as affecting weights and measures officials in New England; H. N. Davis, deputy commissioner of weights and measures, State of Vermont.

Citation by weights and measures officials of important court decisions in their jurisdictions.

Notes on digest of weights and measures cases; William Parry, Bureau of Standards.

Report of committee on nominations, and election of officers.

Report of committee on resolutions.

Report of treasurer.

Unfinished business.

New business.

Suggestions for program of 22d conference.

12:30 P.M. Reception by the President of the United States.

Arrangements for this number are in progress, and it is anticipated that the delegates and guests will be given the opportunity at this time to pay their respects to President Coolidge at the White House.

FIRE TESTS OF RECORD ROOM OCCUPANCY WITH METAL SHELVING.

As a means of obtaining information on the severity of fires in buildings, a number of burning out tests have been

made at the Bureau of Standards in one-story fire resistive buildings constructed for this purpose, the contents simulating light commercial or office occupancy. Notes relative to some of the later tests were published in *Technical News Bulletins* Nos. 114 and 116 (October and December, 1926). As a result of these tests it was found that there should be no difficulty in constructing buildings to resist such fires as ordinarily occur in occupancies employing mainly desks and filing cabinets, in which the weight of combustible materials (including the wood top floor present in some of the tests) amounts to from 10 to 20 lbs./sq. ft. of room area. With larger concentrations of combustible materials, such as in the record and library rooms often found in office buildings, fires of considerably greater severity can occur, as was shown in several tests with records on wood shelving giving total combustible contents of 49 to 59 pounds per square foot of floor area. This condition requires heavier protections than the rest of the building and inasmuch as these concentrations may be placed anywhere within the building the general design would have to take them into account. The tests with metal shelving, which conclude the work with office occupancy, were undertaken to determine to what extent the fire severity from these concentrations can be reduced.

In the first tests, metal shelving representative of several general types was used, nearly one-half of the records being on "skeleton" type shelves having no partitions or backs. Others had partitions but no backs or backs without partitions, and one 29-foot single row had both partitions and backs with doors on two 3-foot bays. All shelving was 8 feet 3 inches high with 5 or 6 shelves, the weight of records in the 15 by 29 foot room being 21,330 lbs. in all of these tests or about 49 lbs. per square foot of floor area. No wood top floor was present in any of the tests with record room occupancy. The fire test was started with a waste paper basket fire in front of a single depth bay open at the front but with metal back and partitions. The window shutters were opened to give the air supply deemed most favorable for fire spread but no general fire condition resulted, the fire when put out at 7 hours 20 minutes, being confined to two 3-foot wide bays with some charred or glowing papers in a cupboard adjacent to one of them.

The affected paper was replaced and two fires were started in piles of waste paper on the floor, one in front of shelving similar to that in the first trial and the other in front of a double depth "skeleton" row. The fire progressed more rapidly than in the first test, particularly in the open shelving and at the end of 1½ hours the whole room was involved. Collapse of skeleton type shelving began at this time and eventually involved all of the shelving that did not have partitions. All combustible contents of the room were completely consumed, the equivalent duration of the fire being, however, less by 25 to 30 per cent. than obtained in previous tests with wood shelving and an equal amount of records.

The room was fitted with new shelving, mainly of the backed and partitioned type with doors every third bay. Three double bays of well braced skeleton type shelving were also included. One test with a slow start for the fire, made in a manner similar to that of the first test described above, progressed laterally through a 3-foot wide cupboard section and another 3-foot wide section with open front in 20 hours, but no general fire spread resulted. A second fire in front of a double-depth open front, backed and partitioned bay spread through a closed front section on each side and involved the whole 18-foot wide stack in about 9½ hours. In this test the window shutters were kept at the lowest opening, and while this retarded the fire at some stages it enabled room temperatures to be built up high enough to cause general fire spread at 13½ hours.

The room was reloaded for tests with "exposure" start for the fire. This condition was approximated by starting a fire in oil-soaked wood kindling filling a grate about 3 feet in diameter and 7 feet high. A shield around it was withdrawn when the kindling was burning freely, the resulting air temperatures in most portions of the room being about the ignition point of paper for 10 to 15 minutes. While fires started at many points they did not progress and at 2 hours the average room temperature was below 100° C. Similar results were obtained in a second exposure start. After one hour the window shutters were closed to their lowest opening and the fires which had started in various portions of the room allowed to go on until air temperatures high enough to

cause general fire spread were built up. This required about 4 hours, the fire in the skeleton bays being mainly responsible for the relatively rapid temperature rise. The contents of the whole room were soon involved, the fire being quite intense but of shorter duration than in previous tests with record room occupancy. No collapse of shelving supports from fire exposure occurred during this test, most of the contents remaining on the shelves until consumed. The equivalent duration of the fire, while considerably above that found in any of the tests with the desks and filing cabinets referred to above, was lower by 35 to 40 per cent. than obtained in comparable tests with an equal amount of records on wood shelving.

The results of all tests with office occupancy are being prepared for publication as a paper in the bureau's technologic series. An outline of the tests and summary of results was given in a paper before the annual meeting of the Building Officials Conference in Detroit on April 25.

RATE OF DEFORMATION OF CONCRETE DURING TEST IN COMPRESSION.

THE rate of deformation of materials during strength test affects the strength values that are obtained, an increase in rate of deformation resulting in general in an increase in strength. This characteristic is apparently connected with the flow or the rate at which the particles of the body will readjust themselves to new positions during strain and is an entirely different phenomenon from the influence of the inertia of the mass of a structure which will permit a much higher instantaneous loading, such as will result from an explosion, than will be statically sustained. Tests by Abrams, described in *Proceedings of the American Society for Testing Materials*, Vol. XVIII, 1917, p. 364, have shown the relation between the strength of various concrete mixes and the velocity of the testing machine head, the actual deformation of the concrete itself not being given.

In connection with the tests on the Santeetlah Dam cylinders, described in *Technical News Bulletin* No. 129 (January, 1928) several of the 6-inch cylinders were tested with

plaster of Paris caps on both ends, and several were tested without capping, the ends having been previously ground to a true plane surface. The idle speed of the testing heads of the machines was .05 inch per minute, generally adopted as standard, and the requirement of A. S. T. M. specification C39–25. These latter machines are equipped, in accordance with the foregoing specification, with a spherical bearing block for the top of the specimen.

The results obtained are tabulated below. Although not shown in the table, the rate of deformation is very slow at first, then increases in value, becoming practically constant and remaining so throughout the greater part of the test. This latter rate has been given in the table. Although it is to be expected that the rate of deformation of the concrete will be less than the speed of the head when the cylinder is capped on both ends with plaster of Paris, the large difference in speeds is surprising, moreover in view of the difference in speeds being maintained through the greater part of the test. The speed difference of head and rate of deformation of the concrete cylinder without caps is even more unexpected.

Rate of Deformation and Testing Machine Head Speeds.

Capacity of Machine (in pounds).	Cylinder Diameter.	Speed of Testing Machine Head.		Rate of Compression of Specimen.	
	in.	in./min.		in./ft./min.	
600,000	18	0.050	Idle speeds.	0.0019	Specimens capped with plaster of Paris on both ends.
				.0021	
"	12	.050		.0028	
				.0035	
200,000	6	.055		———	
		.038		.0038	No cap. Cylinder ground on both ends.
		.044		.0036	
		.018		0.0061	
		.021		.0074	
		.022		.0070	

EFFECT OF BRACKETS IN REINFORCED CONCRETE RIGID FRAMES.

THIS investigation was begun by the Emergency Fleet Corporation of the United States Shipping Board during the

World War, in order to find out how much saving in weight of the transverse frames of concrete ships could be effected by introducing brackets or haunches at the intersections of the members of the frames. At the close of the War the test data were transferred to the Bureau of Standards and a technologic paper giving the results of this investigation is now in press.

Nine frames were tested. All were inverted U-frames hinged at the lower ends of the vertical legs. All had a span of 14 feet and a height of 7 feet. Three frames with no brackets were tested, and two each with brackets 12, 24, and 42 inches long. The length of brackets is measured from the inner face of the vertical leg (or end post) toward the center of the frame, to the end of the bracket. The effect of brackets is sometimes considered as a shortening of the span. This investigation showed that this shortening is not constant for a given size of bracket, but varies also with the ratio of height to span of the frame.

To determine the moments in these frames by exact methods is complicated and tedious but it was found that for a uniform load the moment at the center of the horizontal member is given closely enough for most design problems by a simple empirical equation based on an analysis of the frames.

For the analysis of closed frames or inverted U-frames with legs fixed at the bottom it is shown that the vertical distance from the horizontal member to the point of inflection of the leg may be used in the same equation instead of the height of the freely supported U-frames. The error in the resulting moment is slight. The paper gives a diagram from which the position of the point of inflection for a large variety of frames may be estimated easily.

For other than uniform and centrally concentrated load an analogous method of determining moments through the use of influence lines for the horizontal reaction is developed.

The conclusion is drawn that the results of the tests confirm the theoretical deduction that brackets can be used to effect a considerable saving of material and of dead weight in a structure. The bracket eliminates the high local stress found in the sharp corners of a frame; it produces a more uniform variation in stress along a frame, thus minimizing the tendency toward the formation of cracks; and it reduces

bond and shearing stresses at the corners of the frame. Further, by a careful choice of brackets the bending moment may be varied considerably, and thus a proper balance may be secured between the stresses in regions of positive and those of negative moments.

MEASUREMENT OF TIME OF SET OF CALCINED GYPSUM.

During the course of a recent investigation dealing with the effect of various substances on the time of set of calcined gypsum it became necessary to develop a method for measuring the time of set which would be accurate, dependable, and capable of indicating very slight differences in time of set of different samples.

The Vicat needle penetration test commonly used for measuring this property of calcined gypsum was found not to be of the degree of sensitivity desired. Furthermore, this method gives an empirical value which gives no indication as to the length of time over which the reaction between calcium sulphate hemihydrate and water to form gypsum takes place. H. A. Neville (*J. Phys. Chem.*, Vol. 30, pp. 1037–1042) has shown that the time required for a setting mass of calcined gypsum and water to reach a maximum temperature is a measure of the time required for completion of the reaction:

$$CaSO_4.\tfrac{1}{2}H_2O + 1\tfrac{1}{2}H_2O = CaSO_4.2H_2O.$$

Neville found his point of maximum temperature by inserting a thermometer in a sample of the mix which was contained in a paraffined cup. The cup in turn was insulated to reduce heat losses from conduction and radiation. However, in order that time-temperature rise data may be used to give reliable results on time of set it is necessary to measure temperature rise on samples which are kept as nearly as possible under adiabatic conditions, that is there must be no appreciable loss of heat from the sample to the surroundings.

Some preliminary tests have been made on samples of several sizes, insulated against loss of heat in various manners. All mixes were prepared from the same type of calcined gypsum, were mixed with similar proportions of water, and were initially at the same temperature. Temperatures were

measured with thermometers graduated to 1/10 degree C., inserted directly in the mix. Sample 1 was a 25 gram sample of C. P. calcium sulphate hemihydrate, mixed with 25 cc. water, placed in a small paraffin cup, the whole being well insulated with fibred asbestos. Sample 2 was of the same size as 1 but was placed in a 1 pint capacity thermos bottle during the test. Sample 3 was prepared from 300 grams hemihydrate and 300 cc. water, the whole being mixed in a large. paraffin cup. A thermometer was inserted in the center of the mix and the cup was placed in a 1 pint capacity corked thermos bottle, which was filled with this amount of material.

The data indicated that samples 1, 2, and 3 reached maximum temperatures at 26, 26½, and 38 minutes, respectively. It is evident that for samples 1 and 2 the loss of heat became greater at 26 minutes than the gain of heat due to the crystallization of gypsum, therefore the temperature of the mass decreased before the reaction was complete. Adiabatic conditions were not realized with samples 1 and 2, as their cooling curves clearly indicated. Sample 3, being of much greater mass, lost heat to its surroundings so slowly as to have practically no effect on temperature rise due to crystallization. Under ideal adiabatic conditions the temperature of a setting mass of gypsum would rise to a maximum which would be maintained indefinitely. For sample 3 the temperature drop after this maximum point is reached was 0.0135° C. per minute, although the temperature of the gypsum was about 20° above that of the atmosphere or a sufficiently close approximation to adiabatic conditions. It is believed that such procedure could be used as a measure of time of set.

VITRIFICATION OF CERAMIC BODIES.

AT the Columbus branch of the bureau an investigation of the boundary of the field of mullite in the $K_2O.Al_2O_3.SiO_2$ system is being made. In so far as possible, minerals are being used in making the melts.

The general procedure has been to mix the proper proportions of minerals with dextrin, making a paste which is forced through a glass tube drawn down at one end to about 2 mm.

diameter. This "spaghetti" is then melted in an oxy-gas flame and the beads quenched in water or mercury. The melt is examined microscopically for a crystal phase and the index of the glass measured. The results are then plotted on a three-component diagram.

Melts containing varying amounts of orthoclase, kaolin, and flint (silica) were first made and examined. Mullite crystals were found to occur in melts containing at least 30 per cent. kaolin, those with less being composed almost entirely of glass. There is an almost constant variation in the indices of the glasses ranging from 1.48 with 10 per cent. kaolin to 1.54 with 90 per cent. The amount of mullite crystals increases with the index of the glass. The crystals occur as fibers showing position elongation: indices are $\omega = 1.64$, $\epsilon = 1.66$.

Leucite-kaolin melts show practically the same results as do orthoclase-kaolin melts. Mullite and alumina have been used with orthoclase and leucite. The primary mullite crystals appear in all the melts containing up to 90 per cent. mullite under the conditions of experimenting. When alumina is introduced the mullite crystals appear in melts containing as much as 50 per cent. The appearance of beta corundum near the alumina end of the diagram has been very interesting.

An effort is now being made to make a composition of material corresponding to kaliophilite, $K_2O.Al_2O_3.2SiO_2$, to be used with kaolin, mullite, and alumina in locating the extent of the mullite field in that direction, though as yet the extreme volatility and solubility of potash have prevented success. No detailed work has been done along the boundary lines, as a reconnaissance of the whole field is first being made. Temporary factors as well as volatilization will probably have to be taken into account in later work.

LIGHT COLORED FIRST COAT ENAMELS FOR SHEET IRON.

IN an item on this subject which appeared in *Technical News Bulletin* No. 127 (November, 1927) there were given some results of preliminary adhesiveness tests, showing the effects of treating the metal in various ways before applying

the enamel. Since that time effort has been continued to improve the strength of the enamel-metal bond by treating the metal, and some treatments have been developed which, to cause failure, require loads more than 50 per cent. greater than any reported in the previous item.

Previously reported results showed that adherence was improved by allowing a thin coating of oxide to form over the iron in a furnace before applying the enamel. The application of different cobalt compounds directly to the metal also proved beneficial in varying degrees. Accordingly the combination of both treatments was tried and with better results than were obtained by either treatment alone. Best results were obtained in the application of the cobalt salts when the metal was dipped in a hot solution, and allowed to remain there until it reached approximately the temperature of the bath. Cobalt nitrate appeared to be about the most desirable of the cobalt salts to apply to the iron because it decomposed on the iron with a comparatively gentle heat treatment, and the decomposition product (presumably essentially cobalt oxide) had but little tendency to float in the applied slip and stain the enamel.

The treatment of the metal selected as a standard for a series of tests which will involve a variety of enamel compositions, is as follows: the cleaned metal is dipped in a 5 per cent. solution of cobalt nitrate at about 90° C. (approximately 195° F.) and allowed to remain until the metal is hot. On removal from the solution the piece is whirled and touched on a flat cloth to remove any excess solution from the edges. It quickly dries and is heated in a furnace at 300° C. (about 570° F.) for five minutes. The cobalt nitrate appears to decompose at this temperature when in contact with the iron, and the iron simultaneously acquires a light coating of the oxide. The light-colored enamel is then applied to the treated metal.

Adhesiveness test values have been obtained, with the above and other treatments, which appear quite promising when compared to those obtained with standard cobalt ground coats.

MATERIAL FOR FILLING ETCHED LINES IN THERMOMETERS.

It is a matter of common experience that the materials ordinarily used for coloring the lines and figures on etched stem thermometers are not permanent under all conditions of use. The color in the lines of chemical thermometers burns out at high temperatures, or at lower temperatures is removed by the action of fluids in which the thermometers are immersed. For clinical thermometers, no material has been available which would not be removed by some of the antiseptic solutions ordinarily used.

A new material developed by Paul T. Hannen and H. D. Bruce, of the Bureau of Standards, is much superior in durability to those now in use. It consists of a mixture of water glass and finely divided manganese dioxide which is applied as a paste. A thermometer treated with this material retains the color even when heated to 500° C., and can be used in hot oil, water or steam, without injuriously affecting the visibility of the lines. Clinical thermometers may be treated with any of the common antiseptic solutions without removing this coloring material. The ability of the material to resist attack by acids and alkalies has not been thoroughly tested, but the indications are that it is not entirely resistive to these.

Pigments, other than manganese dioxide, may be used with the water glass to produce other colors.

Application has been made for a patent, dedicated to the public, covering the material and its application. A description of the material and directions for its use are given in a letter circular which may be obtained on application to the Bureau of Standards.

The Compressibility and Pressure Coefficient of Resistance of Ten Elements. P. W. BRIDGMAN. (*Proc. American Academy of Arts and Sciences*, Vol. 62, No. 8.) In most of the measurements the range of pressures was from 0 to 12,000 kg./cm². and of temperatures from 30° to 75° C. The work is the continuation of a program of determining the two properties for all available elements. The compressibilities are about what would be expected from the positions of the elements in the periodic system. In the cases of praseodymium, barium, thorium, chromium, rhombic sulphur, and vanadium the coefficient is larger at 75° than at 30°. The opposite is true for lanthanum and cerium, while for beryllium no difference could be definitely found. The compressibility of red phosphorus at 30° and a pressure of 12,000 kg./cm². was more than four times as great as at the same temperature and a pressure of 2,000 kg./cm². The same holds true when the temperature is 75° for both pressures.

The new data on electrical resistance as a function of pressure introduce fresh confusion into an already confused situation. When the author began his studies all known elements decreased in resistance under pressure with the sole exception of bismuth. Now bismuth has been joined by Sb, Li, Ca, Sr, Cs, Ce and Ba. "The behavior of these new elements only strengthens the view to which I have been coming for some time, namely, that the mechanism of electrical conductivity is not as simple as at first appeared, but that a single type of mechanism is not competent to explain the various behavior of different metals."

G. F. S.

NOTES FROM U. S. BUREAU OF MINES.*

PRODUCTION OF HIGH ALUMINA SLAGS FOR MANUFACTURE OF ALUMINA CEMENT.

THE production in the blast furnace of high alumina slags for the manufacture of alumina cement forms the subject of an investigation recently conducted by the United States Bureau of Mines, Department of Commerce, at its North Central Experiment Station, Minneapolis, Minnesota. The Bureau's experimental six-ton blast furnace was operated on a charge of bauxite, limestone, iron ore, and cast iron turnings. During a three-week test about 70 tons of high alumina slag were produced. The production of this slag offered no difficulty. Blast pressure, an indicator of general furnace operation, was uniformly low. Only moderate blast temperatures were obtained, the average for the period being 885 degrees F. There seems little doubt as to the feasibility of operating a blast furnace on a charge of bauxite, limestone, and iron ore, so as to produce a substantial amount of iron and a slag which falls within the range of composition of alumina cements. The iron oxide in slag made in a blast furnace would differ from alumina cements made by simple fusion of raw materials because most of the iron in the bauxite would be reduced to the metallic state in the blast furnace and recovered under proper conditions as low-sulphur metal. One object of the experiment, conducted by the Bureau of Mines in coöperation with the Aluminum Company of America, was to determine whether the so-called Pedersen process can be applied to the blast furnace. This process consists of smelting a charge of bauxite, iron ore, and limestone, and results in two products. One is a slag containing about 50 per cent. of oxide of aluminum and is intended for use in manufacturing aluminum, and the other is iron low in sulphur.

Blast-furnace slag is now recognized as a satisfactory and economical raw material for making Portland cement. It

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has been reported that in 1926 an important steel interest used well over one million tons of slag in producing about 2¼ million long tons of cement. This is equivalent to about ½ ton of slag for each ton of cement. Alumina cement can be made direct in the blast furnace. Its physical character would have to be changed by grinding, but no change in its chemical composition would be necessary.

This type of cement was of special value to the French Army during the World War for construction of gun emplacements and roads. It is characterized by its high alumina content and high strength at early periods. Since the War interest has steadily increased in its application to general construction work in which time has economic importance. Raw materials and technical details connected with the manufacture of alumina cement and Portland cement differ markedly. Most of the alumina cement is made by secret or patented processes involving partial or complete fusion of the raw materials.

In considering the cost of operating a blast furnace to produce alumina cement the geographical location of the furnace is important. Due to the advantages of obtaining cheap imported bauxite, cost estimates made by the Bureau of Mines have assumed that the furnace site is along the North Atlantic coast. The Bureau's preliminary cost study indicates that 1 ton of metal and 1 to 1½ tons of slag can be produced in the blast furnace for about $25 to $30, allowing no credit for surplus gas. If 1 ton of alumina cement is worth $30 and 1 ton of pig iron $20 the combined value of these two products would be $50, which leaves an attractive margin for grinding the slag, marketing costs, and profit. In addition to the value of the cement and iron produced, a substantial credit for the surplus gas could be obtained in industrial centers or particularly in steel plants.

For the location of a furnace for the use of this process, localities where limestone, bauxite, coke, and scrap can be assembled obviously have a preference for economic reasons. Attention turns at once to the Southern States. The successful beneficiation of high-silica bauxites, a problem under investigation by the Bureau of Mines at its Southern Experiment Station, would make large tonnages of low-grade bauxite

available for the manufacture of aluminum as well as alumina cement.

JAROSITE MINERALS IN OXIDIZED LEAD ORES.

The occurrence of jarosite minerals in the oxidized ores of lead and sulphur has hardly been given sufficient attention by metallurgists, the Bureau of Mines points out. Investigations recently conducted at the Bureau's Intermountain Experiment Station, Salt Lake City, have emphasized the importance of knowing when these minerals occur in the oxidized ores, especially those containing lead, silver, and gold, as their presence is a material factor in selecting a suitable kind of treatment. Since the question of the occurrence of jarosites in oxidized ores has come to the attention of the Bureau of Mines, investigation has indicated that plumbojarosite and argentojarosite are quite common. These two minerals appear to be widely distributed and probably escaped recognition by persons who had attempted to treat certain oxidized lead ores in which the jarosite minerals represented a material portion of the metal content.

Consideration of the physical characteristics of the jarosites also indicates that in many cases failure to treat some of the oxidized lead ores with success has been directly due to the fact that the greater portion of their lead and silver content was present as plumbojarosite and argentojarosite. The data and the description of specimens of these minerals examined by the Bureau indicate that attempts to recover lead and silver from ores in which appreciable amounts of these metals occur as plumbojarosite and argentojarosite would be unsuccessful if confined to gravity methods of concentratiod. There are undoubtedly considerable tonnages of oxidized lean ores in the various mining regions of this and other countries, and it is quite probable that in some of these ores the metal content of lead and silver may be largely anglesite (lead sulphate) and cerussite (lead carbonate) but that they will also contain cerargyrite (silver chloride), argentoiarosite, and plumbojarosite. The treatment of such ores therefore presents an important problem, since a product is discarded from ores from which the recoveries of lead and silver have been

below 70 per cent. which is probably too low-grade to warrant aftertreatment by any process now in use.

Ores containing argentojarosite and plumbojarosite would probably fall in the class just mentioned, and there is ample reason to recommend that the mineralogical character of these ores should be carefully studied and understood before treatment. Where tailings have been discarded which contain 1 or 2 ounces in silver and several per cent. in lead, existing chiefly as jarosites, there is some question as to whether they would stand the expense of any metallurgical treatment now known. Such material therefore represents an economic loss, especially if no care has been taken regarding its disposal, and it may be washed away by flood waters or destroyed by other natural agencies.

The presence of the jarosite minerals in oxidized ores has probably been overlooked by the metallurgist and mill man, who have assumed that the brown color in many ores was due to the presence of the hydrous iron oxides. Undoubtedly many samples of oxidized ores have been cursorily determined by visual observation to be hydrous iron oxide, whereas they probably contained considerable lead and silver in the form of plumbojarosite and argentojarosite.

As the result of the Bureau of Mines' studies, the following conclusions as to the treatment of these ores are given by R. E. Head, microscopist, and Virgil Miller, assistant metallurgist, in Serial 2870:

All oxidized ores of lead, silver, and gold having a reddish-brown or yellow color should be examined to determine whether they contain members of the jarosite group of minerals.

The exceedingly small size of jarosite crystals, their low specific gravity, and their micaceous character render treatment by gravity methods of concentration practically impossible.

Members of the jarosite group of minerals do not sulphidize readily when treated with sulphidizing agents at concentrations commonly used in commercial practice.

Tailings resulting from the treatment of oxidized lead ores on which low recoveries of lead and silver are made should be examined carefully to determine whether the losses are due to the existence of plumbojarosite and argentojarosite.

Jarosite ores which by reason of their relatively low metal content and distance from transportation facilities are of doubtful value may be beneficiated by a type of pyrometallurgical treatment best suited to their characteristics and location. The results of volatilization experiments of several of these ores suggest that this method of treatment should be given consideration.

THE TEMPERATURE OF FLAMES.

The temperatures of stationary flames of various gases and vapors are being determined by the Bureau of Mines by three methods: (1) Reversal of the sodium line; (2) conductivity of the flame when it contains the vapor of a metallic salt; (3) measurement of the temperature of an electrically heated wire in the flame. The work is being conducted to obtain fundamental data on flame propagation and to study methods which may be applicable to the flames from explosives. Measurements on natural gas-air flames showed a temperature of 1880 degrees C. for a 9 per cent. gas mixture and 1760 degrees C. for an 11.4 per cent. mixture. Corresponding calculated temperatures are 2540 degrees C. and 2130 degrees C. The differences between observed and calculated values are due to radiation and conduction losses and uncertainties in the thermal data, and indicate the need for this type of experimental determination. It is planned to measure temperatures of all the commonly used gases and hydrocarbon vapors.

FLOTATION OF LOW-GRADE PHOSPHATE ORES.

An investigation of flotation for low-grade phosphate ores and rejected materials from the Florida washers is now under way at the Southern Experiment Station of the Bureau of Mines. This study has been mainly confined to samples ground to pass 48- or 65-mesh. Samples of rejected materials from all the washers now operating in the land pebble district have been treated in the laboratory with satisfactory results. Concentrates above the minimum grade for commercial phosphate rock—68 per cent. bone phosphate of lime—have

been obtained with recoveries ranging from 83 to 95 per cent. of the phosphate content of the material treated. However, if flotation for phosphates requires fine grinding with the accompanying steps of thickening, filtering, and drying of fine materials, it may prove too expensive for the production of a low-priced commodity such as phosphate rock. Some study is now being made to determine the size of the coarsest grains of phosphate that can be recovered by flotation. In some tests grains of phosphate as coarse as minus 20- and plus 28-mesh in size have been recovered by flotation of unground material. The results obtained, are, however, not consistent. Further study will be required before the amenability of the coarser grains of phosphate to flotation can be determined.

DEOXIDATION WITH SILICON IN THE OPEN-HEARTH FURNACE.

ONE of the primary factors in the rate of elimination of silicates from open-hearth steel is the size of the particle formed on deoxidation. If excess silicon is added to a medium- or high-carbon steel very small glassy particles are formed which rise slowly out of the steel. On the other hand, if there is sufficient iron oxide or manganese oxide to flux the silica, a rapid increase in rate of elimination is found due to the increased size of the silicate particle.

From the results of laboratory work on deoxidation with silicon it is possible to predict just what type of inclusion will be formed with any silicon addition to any type of open-hearth steel, provided manganese is not added at the same time. Predictions from the laboratory work have been checked on various open-hearth heats and out of 67 steel samples studied only six samples showed types different from that predicted. These results make it possible to designate the optimum amount of silicon to add to any open-hearth heat in killing in the furnace and showing that if clean steel is desired certain grades of steel should be killed in the furnace with silicon and manganese rather than silicon alone. Investigation of the properties of the manganese silicates thus formed is now in progress.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Wednesday, May 16, 1928.)

THE stated monthly meeting of the Institute, at which the exercises in celebration of Medal Day were held, was called to order at three-forty-five p.m. by the Senior Vice-President, Henry Howson, Esq.

The Chairman stated that the minutes of the April meeting had been printed in full in the May number of the JOURNAL and that unless there were objection, they would be approved as printed. No objection was offered and the minutes were approved.

The Chairman then called upon the Secretary, Dr. Howard McClenahan, who reported concerning a donation to the Institute of a portrait of Mr. William Sellers, which had been specially painted for the Institute and had been presented by the son of Mr. Sellers, Alexander Sellers, Esq., of Philadelphia. The Secretary stated that Mr. William Sellers had been a member of the Board of Managers of the Institute from 1857 to 1892 and President of the Institute from 1864 to 1866 and that during that time he had been one of the forceful leaders of the affairs of this old society; under his guidance the Sellers, or Franklin Institute, scale of screw threads was proposed and adopted and became the standard of the English-speaking world. The Secretary stated that it is a source of great gratification to the Institute to have this permanent reminder of the distinguished man who had done so much for the usefulness and reputation of The Franklin Institute and that, as the mouthpiece of the Board of Managers, he wished to express the hearty gratitude of the Institute to Mr. Alexander Sellers for his generous and appreciated gift.

The Vice-President then announced that the award of medals was the next order of business and stated that all the medals which had been recommended during the present Institute year by the Committee on Science and the Arts would be presented at this time. The exercises in connection with the presentation of the various medals were then held.

PROGRAMME

	Sponsors
Presentation of Longstreth Medals to	
FRANK N. SPELLER, D.Sc. National Tube Company	Mr. G. H. Clamer
MR. WARREN P. VALENTINE Philadelphia, Pennsylvania	Dr. G. S. Crampton
Presentation of Wetherill Medals to	
MR. ALBERT S. HOWELL The Bell-Howell Company	Mr. W. N. Jennings
FRANK E. ROSS, PH.D. Yerkes Observatory, University of Chicago	Dr. W. R. Wright
Presentation of the Levy Medal to	
VANNEVAR BUSH, MSc., D.ENG. Professor of Electrical Power Transmission Massachusetts Institute of Technology	Prof. H. J. Creighton

Presentation of the Henderson Medal to	
WILLIAM F. KIESEL, JR., M.E. Mechanical Engineer, Pennsylvania Railroad	Mr. G. H. Benzon, Jr.
Presentation of the Clark Medal to	
ARTHUR GRAHAM GLASGOW, M.E. Humphreys and Glasgow, Ltd., London, England	Mr. F. R. Wadleigh
Presentation of Potts Medals to	
EUGENE C. SULLIVAN, PHD. AND MR. WILLIAM E. TAYLOR Corning Glass Works	Mr. C. A. Hall
MR. OSCAR G. THURLOW Alabama Power Company	Mr. F. H. Rogers
Presentation of Cresson Medals to	
VLADIMIR KARAPETOFF, C.E., M.M.E. Professor of Electrical Engineering Cornell University	Mr. C. W. Bates
GUSTAF W. ELMEN, M.A. Bell Telephone Laboratories, Inc.	Mr. C. A. Hall
MR. CHARLES L. LAWRANCE Wright Aeronautical Corporation	Mr. W. L. Brown, 3d
MR. HENRY FORD Ford Motor Company, Detroit, Michigan	Mr. Benj. Franklin
Presentation of the Franklin Medal and Certificate of Honorary Membership to	
PROFESSOR WALTHER NERNST, PH.D., D.SC. Professor of Physical-Chemistry University of Berlin Received by BARON F. VON PRITTZWITZ-GAFFRON The German Ambassador to the United States	Dr. James Barnes
Presentation of the Franklin Medal and Certificate of Honorary Membership to	
CHARLES F. BRUSH, M.E., PH.D., D.SC., LL.D. Cleveland, Ohio.	Dr. James Barnes

PAPERS

"Physico-Chemical Considerations in Astrophysics," by PROFESSOR WALTHER NERNST. Presented by DR. IRVING LANGMUIR, General Electric Company.

"Some Experimental Evidence for a Kinetic Theory of Gravitation," by DR. CHARLES F. BRUSH.

HOWARD MCCLENAHAN,
Secretary.

(An extended account of the proceedings of this Medal Day meeting will appear in the August number of the JOURNAL, in which number the two papers which were read will be published in full.)

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, May 2, 1928.)

HALL OF THE INSTITUTE,
PHILADELPHIA, May 2, 1928.

DOCTOR GEORGE S. CRAMPTON *in the Chair.*

On this date an open meeting was held in the Hall of the Institute to which the local members of the Institute were invited in order to witness a demonstration of the electrical device known as the "Televox." This was given by Mr. R. J. Wensley of the Westinghouse Electric Company of Pittsburgh, Pennsylvania. Mr. Wensley described the device as a system of automatic remote control used by a central station in putting in operation electrical machinery that would perform the duties of an attendant and return notice to the central station when the order had been carried out.

The apparatus was installed on a table by itself. This consisted of the receiving and operating parts and several devices to be operated. By the use of a telephone placed at a distance orders were transmitted by means of whistles of different pitches on receipt of which the following results were obtained: an electric fan was started and stopped; incandescent lights were turned on and off; a projecting lamp was lighted and cut off; a motor was started and stopped; a horn was sounded at will and as long as desired. This demonstration and the lecture that accompanied it were enjoyed by an audience that filled the Hall and which evidenced its approval by enthusiastic applause.

After the retirement of the invited guests the Committee proceeded to the regular business of the Stated Meeting.

The following report was presented for final action:

No. 2859: Waterless Gas Holder.

This is a new type of gas holder, its purpose being to provide a reservoir in which the gas is contained underneath a disk cover which is capable of vertical movement, its position being determined by the amount of gas in the reservoir. This disk carries at its outer edge a shallow trough containing a thick oil or tar which on trickling down the side of the reservoir forms an effective seal between the disk and the side.

A dome-shaped top provides a roof for the reservoir and protects the movable disk from rain or snow. The use of this type of holder avoids the danger of freezing in cold weather to which the water-sealed type is subject and provides a reservoir of constant height.

The oil forming the seal is collected in a circular trough at the bottom of the reservoir and is then pumped to the top where it is distributed for further use as a seal.

The foundations required in this type are not as massive as those for the telescope water sealed reservoir which must sustain the pressure of a high wall of water.

The Waterless Gas Holder has been in extensive use in Europe for a number of years and they have been used in the United States for a sufficiently long time to prove their value in withstanding the conditions brought about by our winters.

The recommendation of the Sub-Committee of Investigation to award the Edward Longstreth Medal to Mr. Konrad Jagschitz, of Mainz, Germany, was adopted.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, May 9, 1928.*)

RESIDENT.

MR. JAMES B. SCOTT, Engineer, Day and Zimmerman, Inc. For mailing: 503 South Forty-sixth Street, Philadelphia, Pa.

MR. KARL B. THEWS, Consulting Chemist, Vice-President, Thews-Harbison-Thews, Inc., 950 Mulford Building, Philadelphia, Pa.

NON-RESIDENT.

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MR. HOLDEN R. HOUGHTON, Industrial Engineering Representative, Industrial Power Department, Consolidated Gas, Electric Light and Power Co., Baltimore, Maryland. For mailing: 1719 North Calvert Street, Baltimore, Md.

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MR. LUCIEN I. YEOMANS, Engineering Building, 205 West Wacker Drive, Chicago, Illinois.

DR. EDWARD L. ZIESEL, 701 South Bonnie Brae Street, Los Angeles, California.

MR. NOEL T. WELLMAN, 36 Prospect Street, Summit, New Jersey.

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BOOK REVIEWS.

NATIONAL ADVISORY COMMITTEE FOR AËRONAUTICS. Report No. 272, The Relative Performance Obtained with Several Methods of Control of an Overcompressed Engine Using Gasoline, by Arthur W. Gardiner and William E. Whedon. 13 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

This report presents some results obtained at the Langley Memorial Aëronautical Laboratory, during an investigation to determine the relative performance characteristics for several methods of control of an overcompressed engine using gasoline and operating under sea-level conditions. For this work, a special single cylinder test engine, 5-inch bore by 7-inch stroke, and designed for ready adjustment of compression ratio, valve timing and valve lift while running, was used.

Tests were made at an engine speed of 1,400 R.P.M. for compression ratios ranging from 4.0 to 7.6. The air-fuel ratios were on the rich side of the chemically correct mixture and were approximately those giving maximum power. When using plain domestic aviation gasoline, detonation was controlled to a constant, predetermined amount (audible), such as would be permissible for continuous operation, by (*a*) throttling the carburetor, (*b*) maintaining full throttle but greatly retarding the ignition, and (*c*) varying the timing of the inlet valve to reduce the effective compression ratio. For the first and third methods, the throttle opening and the valve timing, respectively, were adjusted so that the ignition timing could be advanced slightly beyond the advance, giving maximum power without exceeding the standard of permissible detonation. The optimum

performance for the engine when using a nondetonating fuel, consisting of 80 per cent. of commercial benzol and 20 per cent. of aviation gasoline, was obtained as a basis for comparison.

The following comparative results are based on the optimum performance for the engine obtained with the nondetonating fuel at a compression ratio of 4.7. The power and fuel consumption with method (*b*) remained substantially constant at the higher compression ratios, the order of the ignition timing permitting full throttle operation ranging from 30° at 4.7 to 3° at 7.3; exhaust temperatures, heat loss to the cooling water, and explosion pressures at the higher ratios were normal. At a compression ratio of 7.5, the power obtained with method (*a*) was about 39 per cent. less and the fuel consumption was considerably lower; with method (*b*), time of inlet-valve opening constant and time of inlet-valve closing varied, the power was about 23 per cent. less and the fuel consumption was greatly increased; with method (*c*), time of inlet opening and closing varied simultaneously, the power was about 29 per cent. less and the fuel consumption was greatly increased.

Report No. 273, Wind Tunnel Tests of Autorotation and the "Flat Spin" by Montgomery Knight. 18 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

The following report deals with the autorotational characteristics of certain differing wing systems as determined from wind tunnel tests made at the Langley Memorial Aeronautical Laboratory. The investigation was confined to autorotation about a fixed axis in the plane of symmetry and parallel to the wind direction. Analysis of the tests leads to the following conclusions:

Autorotation below 30° angle of attack is governed chiefly by wing profile, and above that angle by wing arrangement.

The strip method of autorotation analysis gives uncertain results between maximum C_L and 35°.

The polar curve of a wing system, and to a lower degree of accuracy the polar of a complete airplane model are sufficient for direct determination of the limits of rotary instability, subject to strip method limitations.

The results of the investigation indicate that in free flight a monoplane is incapable of flat spinning, whereas an unstaggered biplane has inherent flat-spinning tendencies.

The difficulty of maintaining equilibrium in stalled flight is due primarily to rotary instability, a rapid change from stability to instability occurring as the angle of maximum lift is exceeded.

Report No. 274, The N. A. C. A. Photographic Apparatus for Studying Fuel Sprays from Oil Engine Injection Valves and Test Results from Several Researches, by Edward G. Beardsley. 14 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

Apparatus for recording photographically the start, growth, and cut-off of oil sprays from injection valves has been developed at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics. The apparatus consists of a high-tension transformer by means of which a bank of condensers is charged to a high voltage. The controlled discharge of these

condensers in sequence, at a rate of several thousand per second, produces electric sparks of sufficient intensity to illuminate the moving spray for photographing. The sprays are injected from various types of valves into a chamber containing gases at pressures up to 600 pounds per square inch.

Several series of pictures are shown. The results give the effects of injection pressure, chamber pressure, specific gravity of the fuel oil used, and injection-valve design, upon spray characteristics.

Report No. 280, The Gaseous Explosive Reaction—The Effect of Inert Gases, by F. W. Stevens. 12 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

(1) Attention is called in this report to previous investigations of gaseous explosive reactions carried out under constant-volume conditions, where the effect of inert gases on the thermo-dynamic equilibrium was determined. The advantage of constant-pressure methods over those of constant-volume as applied to studies of the gaseous explosive reaction is pointed out and the possibility of realizing for this purpose a constant-pressure bomb mentioned.

(2) The application of constant-pressure methods to the study of gaseous explosive reactions, made possible by the use of a constant-pressure bomb, led to the discovery of an important kinetic relation connecting the rate of propagation of the zone of explosive reaction within the active gases with the initial concentrations of those gases:

$$s = k_1[A]^{n_1}[B]^{n_2}[C]^{n_3}\cdots.$$

(3) By a method analogous to that followed in determining the effect of inert gases on the equilibrium constant K, the present paper records an attempt to determine their kinetic effect upon the expression given above. It is found that this effect for the inert gases investigated—N_2, He, and CO_2—may be expressed as

$$s = k_1[A]^{n_1}[B]^{n_2}[C]^{n_3}\cdots + \beta[G_i],$$

where $[G_i]$ represents the initial concentration of the inert gas. From results obtained it seems probable that the value of β depends upon the combined effect of the thermal properties of the inert gas on the heat distribution of the reaction, the property of heat conductivity being predominant.

(4) An example of the utility of the constant-pressure bomb for the study of the kinetics of the gaseous explosive reaction is offered in the results of the present paper.

Report No. 281, The Effects of Fuel and Cylinder Gas Densities on the Characteristics of Fuel Sprays for Oil Engines, by Wm. F. Joachim and Edward G. Beardsley. 9 pages, illustrations, quarto. Washington, Government Printing Office, 1927.

This investigation was conducted at the Langley Memorial Aeronautical Laboratory as a part of a general research on fuel-injection engines for aircraft. The purpose of the investigation was to determine the effects of fuel and cylinder gas densities upon several characteristics of fuel sprays for oil engines.

The start, growth, and cut-off of single fuel sprays produced by automatic injection valves were recorded on photographic film by means of special high-

speed motion-picture apparatus. This equipment, which has been described in previous reports, is capable of taking twenty-five consecutive pictures of the moving spray at the rate of 4,000 per second.

The penetrations of the fuel sprays increased and the cone angles and relative distributions decreased with increase in the specific gravity of the fuel. The density of the gas into which the fuel sprays were injected controlled their penetration. This was the only characteristic of the chamber gas that had a measurable effect upon the fuel sprays. Application of fuel-spray penetration data to the case of an engine, in which the pressure is rising during injection, indicated that fuel sprays may penetrate considerably farther than when injected into a gas at a density equal to that of the gas in an engine cylinder at top center.

THE MECHANISM OF HOMOGENEOUS ORGANIC REACTIONS FROM THE PHYSICAL-CHEMICAL STANDPOINT. By Francis Owen Rice, Associate Professor of Chemistry in the Johns Hopkins University. American Chemical Society Monograph Series. 217 pages, 23 x 15 cm., cloth. New York, The Chemical Catalog Company, Inc., 1928. Price, $5.00.

It is to be hoped that this book shall not be the last of a highly commendable class of treatises whose object is to gather and arrange data related to the application of physical science to organic reactions. A. W. Stewart in his "Recent Advances in Organic Chemistry" deplored the fact that researchers in pure organic chemistry have expended so much of their energy toward the synthesis of new compounds and so little toward the purpose of understanding more thoroughly the mechanism of the reactions leading to compounds already known.

Not many years have elapsed since the introduction of the application of physical methods to the study of the structure and reactions of organic substances. A few of these methods, briefly enumerated, are: Light absorption—visible, ultra-violet, infra-red; optical rotation, dielectric constant, refractive index, Tesla luminescence spectra, conductivity in solutions, ionic activity, etc. All these and many other methods furnish the tools whereby the chemist successfully may attack the problem of determining just how a chemical reaction proceeds.

The various types of organic reactions may be classified under two general headings: homogeneous and heterogeneous reactions. The title of Dr. Rice's book: "The Mechanism of Homogeneous Organic Reactions" indicates that he has undertaken an exposition on the kinetics of such reactions. This, he has done in a clear and forceful style. The raison d'etre for this book is aptly described by the author in his preface with the following words: "Reaction kinetics provide us with a powerful weapon for investigating the mechanism of organic reactions and have been freely used for this purpose in nearly all investigations concerning the mechanism of organic reactions. It therefore appeared desirable to make a systematic study of homogeneous organic reactions from this point of view so that the information available would be collected and presented in a more accessible form than scattered through the literature."

Only those who have had occasion to search the literature for all the information published in regard to any particular organic reaction can appreciate what a stupendous task it must have been to cover not one reaction but a collection of all those homogeneous reactions which are well known to the organic chemist. A careful perusal of this book will give a chemist not only a comprehensive view

on all that is known about homogeneous organic reactions but will emphasize simultaneously the enormous amount of knowledge that is still lacking in regard to these reactions.

In the introductory chapter the author does well to remind us that: "Actually our stoichiometric equations hardly ever represent even approximately the reactions that take place in homogeneous solutions because they invariably neglect the possibility of compound formation between solvent and dissolved substances; also in these stoichiometric equations the existence of the catalyst is usually ignored, this being justified by some such manifest untruth as: 'The chemical nature of a catalyst is unchanged at the end of the reaction.'"

The author takes as his major premise the assumption that: The mechanism of organic reactions in homogeneous solution may be pictured to be a rate of collision between dry hydrogen or hydroxyl ion and various solvated and unsolvated forms of the reactants. The author then attempts to explain the data for each reaction in the light of the above statement. His procedure seems to be justified by the fact that there is no mechanism of homogeneous catalysis upon which all chemists are agreed and that such procedure makes possible a more unified treatment of the subjects discussed. Only by carefully reading the book can one realize the adeptness with which the author has logically explained the various anomalies observed in organic reactions by means of this adopted postulate of his.

Chapter II, following the introduction, deals with the general characteristics and factors governing reaction velocity. Chapter III is devoted to "Addition Compound Formation" and contains a mass of data emphasizing how extensively addition compounds occur in organic solutions. Chapter IV, "Theoretical," contains brief descriptions of the various theories which have been advanced to explain just how the reactants of an organic reaction react. The remaining chapters deal with the better known types of homogeneous organic reactions such as isomeric change, hydrolytic reactions, reactions of aliphatic hydrocarbons, of benzene and its derivatives; general reactions such as Friedel and Crafts, acetal formation, reactions involving aldehydes, the Perkin and Claison condensations, the Michael reaction, Hoesch's synthesis and the Hell-Volhard reaction. The last chapter headed, "Special Topics" deals with the Walden Inversion, Beckmann Inversion and includes a well written discussion upon chemical reactivity.

To a chemist seeking suggestions and aid in regard to research problems this book should prove to be of inestimable value. For in it he or she will find a thorough digest of the literature and references on each topic and a clear indication as to the next phase of the problem which should be investigated. Such a book surely will prove a stimulation to all thinking chemists concerned with fundamental problems of homogeneous organic reactions. And what chemist isn't? THEODORE K. CLEVELAND.

THREE LECTURES ON ATOMIC PHYSICS. By Arnold Sommerfeld, F.R.S., Professor of Theoretical Physics at the University of Munich, translated by Dr. Henry L. Brose. 70 pages, 18 x 12 cm., cloth. New York, E. P. Dutton and Company. Price, $1.

In the hands of its proponents, developments are continually proceeding in the processes of analyzing the mechanism of the new theory of atomic structure.

These lectures on atomic structure were delivered at the London University to meet the desire of that institution to secure the present views on current problems of atomic physics of the noted investigator whose contributions on this most fundamental basis of physical science occupy a foremost position. In the first lecture "General remarks on atomic physics, in particular on the spectra of hydrogen and helium" the author explains how the various quantum numbers that are required for describing spectra are introduced, and the analogy of the structure of the hydrogen atom to that of the alkali metals is pointed out, in harmony with which he develops a new theory for the hydrogen atom. The author remarks in his introduction: "What are at present the most acute questions of atomic physics? First and foremost we may certainly place the problem of the nature of light. . . . Another acute question is that concerning the validity of mechanics. We feel certain that nature is much simpler and more regular than can be explained by classical mechanics when applied to atomic systems. It appears that the quantum mechanics which is now in process of development will bring us help."

The second lecture, "The general system of the complex terms" relates to the derivation of a system of terms applicable to higher multiplicities and to the "principle of uniqueness" of Pauli. The third lecture, "Chemical bonds and crystal structure" considers the theory of the periodic system of the elements which shows in what elements completed subgroups are to be expected.

To investigators of atomic theory, Professor Sommerfeld's recent views on the development of the subject should prove inspiring to further advances.

L. E. P.

MOLECULAR PHYSICS AND THE ELECTRICAL THEORY OF MATTER. By James Arnold Crowther, M.A., Sc.D., F.Inst.P., Professor of Physics in the University of Reading. Fourth edition, viii–202 pages, 18 x 12 cm., illustrated, cloth. Philadelphia, P. Blakiston's Son & Company, 1927. Price, $2.50.

Those who cast about for an intelligible account of the evolution of the electrical theory of matter or what has come to be known as the "new physics" will be generally disappointed at the magnitude of the task of a perusal of any of the works which contain the results of the investigations and the deductions of the celebrated scientists who have contributed to the already extensive literature of that subject. The fundamental facts of science being inferential and deductive, are not capable of definition and intelligible explanation in a few words. As with the old atom, which requires a consideration of Dalton's law and the hypothesis of Avogadro for its explanation, so with the new atom with its greater complexity a still more extensive collection of inferential facts and a far more elaborate array of deductive devices are requisite for its satisfactory elucidation.

Professor Crowther's book meets the demands of a wide diversity of readers. Those who desire a general account of the investigations from which deductions have been made which are bringing the theory of the new atom on an operative basis will find it there presented in simple and straightforward language and free from difficult mathematical operations. To the serious student a better introduction could scarcely be asked than the survey which the author makes of the classical researches which have inspired the electron atom.

Beginning with a historical outline, the author proceeds to the physics of

the electron which begins with the vacuum-tube phenomena of Crookes, the explanation of positive particles and positive ray analysis. Then the nature and size of an electron, the structure of the electron and the structure of the atom are discussed. At this point he gives a chapter on the electron in chemistry in which are included Thomson's theory, the grouping of electrons and their relation to the periodic classification and the electrical theory of valency. With this groundwork we pass to the atom in vibration, the quantum theory and Bohr's theory of stationary orbits, the molecular theory of matter and radio-active transformations.

The work is indeed a very complete summary of the molecular theory of physics. ("Molecular" the author explains is here used in its strictly etymological sense) which answers most fully the question "What is an Atom?"

LUCIEN E. PICOLET.

PILES ET ACCUMULATEURS ÉLECTRIQUES. Par Lucien Jumau, Ingénieur. Collection Armand Colin No. 55. 194 pages, 17 x 11 cm., paper, illustrated. Paris, Librairie Armand Colin, 1928. Price, bound 10 f. 25, paper 9 f.

There are few departments of electrical engineering, if any, in which some application of storage batteries may not be found. A knowledge of the theory, construction and management of accumulator installations is consequently an important branch of an active practitioner's professional qualification.

Considering its dimensions, there is an extraordinary amount of both theoretical and practical information in this compact little volume. The book is in two parts, the first on primary batteries, the second on accumulators. In the forty-eight pages of the first part are considered the general principles, thermodynamic relation, theory of ions, efficiency and the like, and much practical data on the components of primary batteries. Illustrations of the more important batteries which have survived the test of time are described with charts of performance. Among these, the *pile* Féry whose chief characteristic is depolarization by oxygen from the air is of especial interest. In the second part we have first the theory of the lead accumulator, its characteristics, capacity, life and efficiency followed by an examination of various elements and electrolytes. Constructive, structural and manufacturing features of lead batteries then are treated at considerable length. An account of the Edison battery and an ample section on installations conclude the work. A bibliography with one exception from French sources is appended.

LUCIEN E. PICOLET.

MOVING COIL LOUDSPEAKER, COMPLETE CONSTRUCTIONAL DETAILS AND DIMENSIONAL DRAWINGS. By F. H. Haynes, Assistant Editor of "The Wireless World." 32 pages, 22 x 14 cm., paper. London, Iliffe & Sons, Ltd. Price, 1/6.

Since the first introduction of the loudspeaker when the radio devotee was content with headset reception, a steady improvement has continued in the performance of that device, and loudspeakers of several makes in this country since the last few years have yielded a quality of performance quite satisfying to the majority of users. These are now generally of the paper-cone type operated by a somewhat enlarged telephone receiver. The speaker here described, for which great fidelity of tone-reproduction is claimed, is also of the paper-cone

type and is apparently of American origin. Here, the vibration of the cone is effected by a coil integrally fastened to the small base of the frustum which receives the pulsating current from the radio set. An energizing magnet of the iron-clad type positioned in proximity with the moving coil and axially with it produces the required intense field. The device is described in a paper published in the *A. I. E. E. Journal* for September 1925.

A very complete description of the details of construction is given illustrated by well executed drawings, but a longitudinal section of an assembly which is omitted would have added much to the clarity of the description. The cost of the machined castings and other materials exclusive of labor is given at £4–5–0.

LUCIEN E. PICOLET.

THE CALENDER EFFECT AND THE SHRINKING EFFECT OF UNVULCANIZED RUBBER. By Dr. W. De Visser, translated from the original Dutch by Edward S. Allsop, sworn translator, Hilversum, Holland. viii–152 pages, 21 x 14 cm., cloth. London, Crosby Lockwood and Son, 1926. Price, 15/.

The value of a monograph which analyzes the technique of an important phase of manufacture in a major industry like that of rubber whose varied uses are familiar to everyone is obvious. One of the several processes through which the material which constitutes the product passes is known as "calendering." In this process as described by the author "the warm plastic mixture of rubber, sulphur, compounding ingredients and accelerator is rolled into a uniform sheet of the desired thickness. The articles to be vulcanized later are made from these sheets." The work deals with a critical examination of the effects of calendering, the difference of the stress-strain curve, with and transverse to the direction of rolling, the unequal change of form in the length, breadth and thickness of the sheet, and the irregular deformation of pieces for the manufacture of articles which are cut from unvulcanized sheets.

After a review of the technical importance of the subject and a survey of the literature of experiments on calender effect, the necessary conditions of production, control and examination of the material as affected by the process are minutely analyzed. Well-executed half-tones, sketches, many stress-strain diagrams and numerous tables are included. There are also numerous bibliographical references To the specialist in rubber manufacture this searching analysis should prove of rare interest.

L. E. P.

MAGNETISM AND ATOMIC STRUCTURE. By Edmund C. Stoner, Ph.D. (Cambridge), Lecturer in Physics at the University of Leeds. xiii–371 pages, 22 x 14 cm., cloth, illustrated. New York, E. P. Dutton and Company. Price, $5.

As early as the time of Ampère we had the suggestion of molecular currents as the cause of permanent magnetism, and with the opening of the present century, the work of those celebrated investigators who discovered the electron and demonstrated its properties initiated the remarkable evolution in atomic physics of which one phase is the generous collection of fact and deduction in the application of atomic theory to the interpretation of magnetism. In this work is set forth an account of magnetic phenomena and their formulation in terms of the quantum theory. The large amount of work which has been done in this field

precludes the discussion of more than representative researches of which a sufficiently comprehensive account is given to enable the reader to follow its further development. No review is made of the subject-matter of the numerous texts on magnetism as usually presented and the general phenomena of ferromagnetism receive only brief reference.

After an introductory chapter which is a model of concise thoroughness, an account is given of the classical electromagnetic theory and the earlier methods and results. The interpretation of magnetism as an atomic phenomenon is then developed, followed by an analytic review of the quantum theory and a survey of experimental results made during the period of evolution of the quantum theory. Among the topics of the ten succeeding chapters may be mentioned: Quantum and Weiss magneton number; Magnetic deviation of atomic rays; The Zeeman effect and other magneto-optical effects; Diamagnetism; Magnetism and the structure of the atom. Under these headings and others, the author makes a fully detailed presentation of the most recent investigations, many of which have been available only in original papers. For the benefit of the reader, who should possess a considerable degree of mathematical proficiency, the author has described quite fully the coördinate and vector methods of procedure which are employed throughout the book. The work constitutes a well-balanced and thoroughly documented account of recent progress in the study of atomic magnetism. L. E. P.

THE RISE OF MODERN PHYSICS, A POPULAR SKETCH. By Henry Crew, Ph.D., Fayerweather Professor of Physics in Northwestern University. xv–356 pages, 18 x 13 cm., cloth. Baltimore, The Williams and Wilkins Company, 1928. Price, $5.

Treatises on physics are concerned with the science as it is and dwell only briefly upon historical facts. That the lessons of the past are of value is generally admitted, and how much of one's time should be taken from the major task of dealing with the new and important matters of immediate interest to acquire a just perspective of the subject by some attention to the past is a problem which this volume aids materially in solving. The burden of the student of science is a heavy one but the informal and fluent character as well as the scholarly method of this narrative which will impress the reader with its quality will go far to lighten the additional task and prove rather a diversion of compelling interest. Beginning with the pre-Greek period when the contributions to physical science were mainly of a utilitarian character which received no formulation that in any way resembled a physical law, Dr. Crew depicts the influence of that immortal group of scholars of the Alexandrian period, Pythagoras, Euclid, Archimedes, Hipparchus and Claudius Ptolemy, as well as other notable figures in Greek and Roman science. It is in this period, we learn, that while geometry and trigonometry bore a close resemblance to processes in use to-day the first electric current was two thousand years in the future. After noting the contributions of the Arabs, an outline of medieval science follows in which are included the enduring names of Roger Bacon, Leonardo da Vinci, Copernicus, Tycho Brahe and Kepler.

Then comes the birth of modern physics with Galileo, Huygens and Newton which are more or less familiar to a student of physics. Their work and that of

others like d'Alembert, Snell, Young and Fresnel is recorded in its proper relationship and with reference to the circumstances and influence of the times in which they lived. The rest is more commonplace in its modernity and the famous names concerned with that period are many-fold in number that of previous periods but the narrative continues with undiminished zest. The early work of the pioneers in electricity and magnetism is recorded, the laws of Coulomb, Gauss and Weber. This is followed by heat, thermometry, electromagnetism, and finally the great strides which have been made in the atomic theory and its relation to electricity, magnetism and the extraordinary developments of spectroscopic investigation.

Twenty-four portraits of celebrated physicists contribute a desirable touch of human interest. A brief but representative bibliography and numerous references with the text will prove helpful to the serious reader. The work is of especial value in a school course in that it represents, as the author expresses it, an irreducible minimum for a just perspective of the past in physical science. The readable style in which it is written will prove equally attractive to the general reader.

LUCIEN E. PICOLET.

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CURRENT TOPICS.

On the Union of Helium with Mercury. J. J. MANLEY. (*Phil. Mag.*, Oct., 1927.) When the glass tube of a mercury barometer is moved up and down, its lower end remaining always beneath the surface of the liquid in the vessel open to the air, electric charges are developed upon the glass. If a little gas is present between the mercury and the closed tube above it, a feeble glow appears. There is usually in addition some chemical action that causes a reduction in the gas pressure. In many cases a stain is seen upon the walls of the tube and later a solid deposit forms there. When the contained gas is oxygen, nitrogen or air, the deposited solid consists of "mercury oxide, a stable nitride of mercury or a compound containing both mercury and ammonium," respectively. With very pure hydrogen in the tube the friction of the glass upon the mercury may be continued for hours without causing anything more than the glow, but after very long action a pearl-like luster appears on the glass, which is so transient that it cannot be chemically analyzed. The author believes it to be a hydride of mercury. The experiments just cited were performed by attaching the barometer tube to a pin some distance from the axis of a pulley rotating about a horizontal axis.

Other experiments were carried out with pure helium as the gas in the tube, the purpose being "to illustrate the correctness of the views universally held concerning the observed chemical inertness of the gas." After the tube had moved up and down for a long time there was no change in the appearance of the glass surface but a surprising thing had occurred: the pressure of the helium had grown less and that by no microscopic amount. The initial pressure was 7 mm. and the final amount 2.3 mm. It seemed difficult to explain the observed reduction of pressure except by assuming the formation of a helide of mercury but so radical a hypothesis demanded more thorough investigation of the facts. A more complicated apparatus was accordingly constructed and used. "The barometric tube executed some 7,000 or more strokes per hour." The results confirmed the author's belief that "at low pressures and in the presence of a glow-discharge helium is capable of uniting with mercury." The helide thus produced was not condensed at the temperature of liquid air but it did cause some kind of a skin upon the surface of the glass. The reduction of pressure observed

with the improved apparatus was by no means as great as with the original form.

Since the helide seemed to be formed in a glow discharge, several ways of applying this were tried. Most of them were useless but one or two gave good results. By the use of one the weights of the combined mercury and helium were determined and found to be respectively .236 and .047 mg. There is evidence for the existence of one helide with the formula $HgHe_{10}$, and of another with the simpler composition HgHe or $HgHe_2$.

Experiments in which argon replaced helium showed that this gas does not combine with mercury. G. F. S.

A Redetermination of the Newtonian Constant of Gravitation. PAUL R. HEYL. (*Proc. Nat. Acad. Sciences*, Aug., 1927.) The author of this paper was years ago the recipient of part of the Boyden Premium of The Franklin Institute. He was one of the inventors of the inductor compass used by Lindbergh in his trans-Atlantic flight. It was his father who in the early 70's of the last century gave in the Academy of Music, Philadelphia, an exhibition of moving pictures long before Eadweard Muybridge's work under the auspices of the University of Pennsylvania.

For a generation the accepted value of the constant of gravitation has had joint and concordant support in the independent results of C. V. Boys in England and Carl Braun on the continent. They agreed to four significant figures in finding the constant equal to 6.658×10^{-8} dynes, that is, two gram masses concentrated at points one centimeter apart attract each other with a force of 6.658×10^{-8} dynes. While the averages of their results were so exactly alike, still in the case of both men the separate results used in calculating the averages differed considerably from one another. This led Poynting to assign the value 6.66×10^{-8}, with the possibility of one unit error in the second decimal place. Since the Newtonian constant underlies all the complex interactions of the solar system and indeed the whole starry universe, Dr. Heyl has thought it well to endeavor to push the determination of its value to a further decimal place.

He uses the torsion balance so often used in such work since the days of Lord Cavendish. Boys measured the permanent deviation from the neutral position produced by the attraction of two large masses on two smaller masses located at the ends of a light horizontal beam supported by a vertical wire or thread, and seemed to have carried the accuracy of his method as far as it could go. On the other hand Braun felt that he had not reached the limits of

his method. Dr. Heyl consequently adopts this suggestion, and follows Braun in his arrangement of the apparatus and in his reliance upon a change in the period of oscillation of the torsion pendulum caused by a shift in the position of the two large masses. The two relative positions of the two large attracting masses, M, with respect to the two small masses, m, located at the ends of the horizontal beam of the torsion pendulum are as follows: $M\ m\ m\ M$ and $m\ \begin{matrix} M \\ \\ M \end{matrix}\ m$. In the absence of the masses M the beam when displaced horizontally will swing to and fro under the influence of the torsion of the suspending wire, but in the presence of the two large masses their attraction upon the smaller masses will be compounded with the torsional force, and the period of oscillation for the first position above given will be different from that for the second. In Braun's work this difference amounted to 46 secs. His large masses were about 9 kg. each. By employing masses of 66 kg. while leaving practically unchanged the other quantities concerned, Dr. Heyl raised the period to 330 secs. The work was carried on in a constant temperature room at the Bureau of Standards, 35 feet underground. To avoid the presence of blow holes in the steel cylinders forming the two large attracting masses, they were forged down from 12 to 9 inches in diameter. The horizontal beam of the torsion balance was so designed that 99 per cent. of its moment of inertia was in the balls at its ends. The supporting wire was a filament of tungsten a meter long. Boys used a thread of silica but it was hard to manipulate and broke without apparent cause. The procedure for getting the torsion balance to swing presents a very vivid proof of the existence of gravitational attraction between bodies of non-planetary size. "To start the pendulum swinging, gravitational attraction was employed. Two bottles holding about 2 kg. mercury in each were placed in the maximum attraction positions and changed to the opposite sides of the pendulum in time with its swing. By repeating this process for two hours it was possible to produce an amplitude of $3\frac{1}{2}$ degrees."

Observations made in 1926 gave as values of the constant the following, all to be multiplied by 10^{-8}—6.661, 6.661, 6.667, 6.667 and 6.664, mean 6.664. "No previous investigator has obtained results agreeing to more than two significant figures." This is an accomplishment that reflects great credit upon the American scientist to whose skill and patience it is due. G. F. S.

Standardization of Cod Liver Oil. WALLACE H. DICKHART (*Oil and Fat Industries*, 1928, *5*, 82–84) has modified his uranium nitrate test which has been noted in Journal of the Franklin Institute, 1927, *204*, 820. In the modified test, use is made of a 6-inch test tube with an internal diameter of 20 mm. The oil (3 c.c.) and the uranyl nitrate (10 mg.) are placed upright in a 400 c.c. beaker containing 80 c.c. of water which has been heated so that it just boils. The tube is kept at this temperature for 20 minutes, then cooled, and the color of its contents measured. Certain grades of sardine oil yield a deep green color like that of chlorophyll at the end of 2 minutes in this test; this color becomes a deep red on further heating. Dickhart proposes the following standards, the color measurements being made in a Wesson tintometer using standard Lovibond glasses:—For *medicinal cod liver oil*, a maximum of 1 yellow 0.1 red before testing in the modified manner, and 35 yellow 3.8 red after heating as described above. For *poultry oil*, 1.5 yellow 0.2 red before testing and 35 yellow 5.0 red after heating.

J. S. H.

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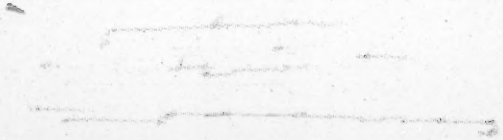
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